

**GEOHERMAL POWER  
DEVELOPMENT IN HAWAII.**

**Volume I.**

**Review and Analysis**

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Department of Planning and Economic Development  
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## FOREWORD

By Hideto Kono  
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Hawaii imports about \$1.5 billion in petroleum each year to provide the energy it needs. Meanwhile, there are all around us prodigious alternate energy resources awaiting development. These include the sun itself; the wind; the heat of the earth, especially in our volcanic region on the Island of Hawaii; biomass--the things which grow from our fertile soil--and ocean thermal energy conversion.

This new volume reviews and analyzes geothermal power development in Hawaii. It is one of a number of reports during the past few years which throw light on ways in which Hawaii can become more self-sufficient in energy. This is essential work, preparing the way for reduced dependence on imported oil. This work can mean greater economic stability for our Islands and greater economic freedom for Hawaii's people.

I am grateful to all who have contributed their considerable expertise to the preparation of this volume. It makes even stronger the base of information and assessment upon which wise decisions can be made regarding geothermal power plants and power distribution systems.

## INTRODUCTION

This report--one of two related volumes--presents information derived during the first year (1980-1981) of a two-year project of reviewing and analyzing various aspects of geothermal energy in Hawaii. It addresses specific tasks set forth in work agreement No. DE-FC03-79ET27133 of a project funded by the U.S. Department of Energy and conducted by the State of Hawaii Department of Planning and Economic Development (DPED). The DPED's project manager was James L. Woodruff. The report consists of the condensation of several studies performed by the consultants listed below. It is intended not only as an information document for the U.S. Department of Energy, but also as a reference for a wide audience of planners, investors, legislators and other decision-makers.

The other volume address infrastructure and community services requirements to accommodate the development of geothermal energy for the Island of Hawaii for the production of electricity.

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## I. THE HISTORY OF GEOTHERMAL EXPLORATION IN HAWAII

The recognition and use of geothermal energy in Hawaii has been recorded well back into the history of the Hawaiian Islands. Explorers identified numerous fumaroles and thermal features on Kilauea and Mauna Loa volcanoes as early as 1827 (Ellis, 1827) (Guppy and Salcombe, 1906). The use of the Kilauea summit fumaroles for a variety of cooking and heating purposes extends back into the times of the pre-contact Hawaiians and has been virtually continuous up to the present time (Olson, 1941). However, largely as a result of the relatively small number and low temperatures of Hawaii's surface thermal features, very little serious geothermal exploration or research was conducted until the early 1960's.

In 1961, four privately financed exploratory wells were drilled into the Kilauea east rift zone by Hawaii Thermal Power Company (Stearns, 1966). All these wells encountered temperatures well above that expected for normal groundwater (Table 1), but because of their shallow depth none were of sufficient temperature to be considered economically exploitable; all were capped and abandoned. After this effort most geothermal exploration in Hawaii, has until very recently, been government-sponsored research into the nature and occurrence of geothermal systems in Hawaii.

In 1973 the National Science Foundation sponsored a geothermal research project which was conducted at the summit of Kilauea volcano by Dr. George Keller of the Colorado School of Mines. A research well located 1.1 km south of Halemaumau Crater was drilled to a depth of 1262 m (approximately 160 m below sea level). The maximum temperature encountered at the bottom of the well was 135°C, and the temperature gradient (the increase in temperature with depth) observed over the last 150 meters of the well was approximately 370°C/km (Keller, 1976). If drilling had continued to only slightly greater depths much higher temperatures almost certainly would have been encountered. However, in that the objectives of this well were directed toward basic research, the project was considered to have achieved its goals and thus no subsequent efforts have been made to deepen the well.

It was also during this period that the University of Hawaii, under a research grant from the National Science Foundation and the State of Hawaii, began an exploration program for a second geothermal research well. Although geophysical and geochemical surveys were initially conducted in several parts of the Big Island of Hawaii, it rapidly became apparent that the east rift zone of Kilauea volcano had the greatest potential for success

TABLE 1

## GEOTHERMAL EXPLORATION AND RESEARCH WELLS IN HAWAII

U.S.G.S. Well No.	Name	Depth/ Elevation (meters)	Maximum Temp (°C)	Year Drilled	Drilled By	Status
2686-01	Geothermal 1	54.3/307.5	54 <sup>0</sup>	1961	Hawaii Thermal Power Company	abandoned capped
2686-02	Geothermal 2	169.5/315.5	102 <sup>0</sup> (97.1 <sup>0</sup> )	1961	Hawaii Thermal Power Company	abandoned capped
2982-X	Geothermal 3	210.3/171.6	93 <sup>0</sup> (92.5 <sup>0</sup> )	1961	Hawaii Thermal Power Company	abandoned capped
3081-02	Geothermal 4	88.4/76.2	43 <sup>0</sup>	1961	Hawaii Thermal Power Company	abandoned plugged
2317-01	NSF-Kilauea	1262.2/1102.2	137 <sup>0</sup>	1973	Colorado School of Mines/GEDCO†	abandoned plugged
2883-01	HGP-A	1967.5/184.1	358 <sup>0</sup>	1976	University of Hawaii/GEDCO†	producable
4650-X	Steamco 1	1889.8/777.2		1979	PuuWaawaa Steam Company/GEDCO†	abandoned capped
4850-X	Steamco 2	2072.6/725.4		1979	PuuWaawaa Steam Company/GEDCO†	abandoned capped
2655-X	Ashida 1	*/244.8	*	1980	Barnwell Industries/ GEDCO†	*

†GEDCO = Geothermal Energy Development Company

\*Data is not publically available

and thus the majority of the detailed exploration work was confined to this area (Keller, et al., 1977). A substantial quantity of data was obtained throughout the largely geophysical exploration program. From this data several areas were identified along the lower east rift zone which were interpreted to have conditions indicative of a geothermal reservoir. However, no single site could be positively identified as having a geothermal resource.

Despite some disagreement in the various interpretations of the subsurface conditions, a decision was made to drill a single deep research well into the lower east rift approximately 1 km west of the prehistoric cinder cone Puu Honuaualua. This location was chosen primarily on the basis of numerous shallow warm water wells in the vicinity, nearby resistivity and self-potential anomalies, and the availability of land for a drilling site (Macdonald, 1976). Drilling was initiated in December 1975 and was completed by late April 1976. The well was named Hawaii Geothermal Project Well-A, (HGP-A) in honor of the late Dr. Agatin Abbott, the chairman of the site selection committee. Downhole temperature measurements made after the well was completed indicated that the well was definitely hot, and on July 2, 1976, the well was artificially induced to discharge a mixture of steam and hot water. Numerous tests conducted on HGP-A since 1976 have shown that it is by far the hottest well in the United States, having a maximum bottom hole temperature of approximately 358°C, and that the well is capable of producing over 45,000 kg/hr of steam (55%) and water (45%) (Kroopnick, et al., 1978) (Chen, et al., 1980).

Construction of a 3 megawatt wellhead generator facility as a proof of feasibility project was jointly sponsored by the U.S. Department of Energy, the State of Hawaii and Hawaii County. The installation of the generator was completed in early 1981, and production of electric power began in mid-1981 (Figure 1). The objectives of the wellhead generator project are to identify and surmount both the real and the perceived barriers to the production of power from the Kilauea east rift and thereby stimulate private interest in the development of the discovered resource.

After the successful drilling of the HGP-A well a major exploration effort, jointly sponsored by the U.S. Department of Energy and the State of Hawaii, has been directed toward the identification and the characterization of other potential geothermal resources throughout Hawaii. The initial phase of this work consisted of a compilation of available data relevant to the identification of potential geothermal areas. On the basis of the initial reconnaissance survey, twenty areas within the State were selected as targets for more extensive detailed field surveys (Thomas, et al., 1979).

FIGURE 1

HGP-A WELL AND POWER PLANT

FIGURE 1

HGP-A WELL AND POWER PLANT



Private interest in geothermal exploration and development in Hawaii increased substantially after the successful completion of HGP-A in 1976. Privately financed exploration drilling was undertaken on the northwestern flanks of Hualalai volcano on the western side of the Big Island in the early part of 1978 by the Puu Waawaa Steam Company. Prior to drilling, several geophysical surveys were conducted around the Puu Waawaa cinder cone by a mainland-based exploration group; several geophysical anomalies were observed in this area, and two exploratory wells were drilled (Craddick, 1980). Neither well encountered significantly elevated temperatures to depths of more than 2,000 m and both were abandoned shortly after completion.

More recently, several permits for exploratory wells in the immediate vicinity of HGP-A have been obtained by other private groups. Two of these wells have been completed and are believed to have encountered high subsurface temperatures. However, since these wells are a private venture, no information is available concerning subsurface temperatures or the nature of the resource encountered.



## II. THE NATURE OF THE GEOTHERMAL RESOURCES IN HAWAII

Geothermal energy, very simply defined, is that energy which can be obtained from heat within the earth. It is generally understood that the solid, relatively cool crust of the earth is underlain by several progressively hotter and denser layers of material. The source of the earth's heat is a combination of (1) the energy released by the decay of the small concentration of radioactive elements trapped within the earth and (2) the thermal energy released when the original protonebular dust cloud coalesced to form the earth. If one were able to drill through the crust of the earth the temperatures encountered would gradually increase with depth; the temperature gradient observed through the crust would average 20°C-30°C per kilometer in depth (Bott, 1972). Thus, under most circumstances, exploitable temperatures would not be reached above 5-10 km depths in most areas of the earth. In several places, however, the normal stability of the mantle and crust has been upset, resulting in the formation of bodies of molten rock (magma) which migrate upward into the crust. When this molten magma reaches the surface of the earth, volcanic eruptions occur and the heat energy carried up from the earth's mantle is very rapidly dissipated into the atmosphere (Williams and McBirney, 1979). However, if the molten magma body begins to solidify before it reaches the surface, its thermal energy is slowly released to the near-surface rocks and groundwater. Under favorable conditions a relatively long-lived (thousands to millions of years) geothermal system can be formed by the interaction between slowly cooling magma bodies and near-surface groundwater.

There are several types of geothermal systems that have been identified in relation to volcanic and subvolcanic processes. The most common type is the water-dominated system, which is characterized by a reservoir of warm to very hot water confined by a low-permeability cap rock or by the hydrostatic pressure of an overlying layer of cooler groundwater. If sufficiently high temperatures are present, both hot water and steam can be recovered from these systems by drilling into the reservoir. Such liquid-dominated geothermal systems are known to exist in several parts of the United States (including Hawaii) as well as in New Zealand, Japan, and numerous other countries (Armstead, 1978).

A second, less common, type of thermal reservoir is the vapor-dominated system; it is characterized by both a high heat flow and a low groundwater permeability. Geothermal fluids in a vapor-dominated reservoir are often nearly 100% steam with only very small amounts of liquid water (and other naturally occurring volatile compounds). Vapor-dominated systems are known to occur in only a few places around the world. Larderello, Italy, and Geysers, California are examples; none are presently known to exist in Hawaii.

A third major class of geothermal resource is the hot dry rock system. These areas are similar to the vapor-dominated type in that they are also characterized by a low groundwater permeability. However, they have so little groundwater present and their permeability is so low that in order to extract heat from them, it is necessary to artificially induce permeability by fracturing the rock strata and then circulating water from the surface through the induced fractures. The development of the technology necessary for the exploitation of this type of resource is still in the experimental stage. The extraction of heat from molten magma bodies (a subclass of the hot dry rock system) is also being considered. Large quantities of heat are contained in such near-surface bodies. They are known to exist in Hawaii (i.e., Kilauea east rift zone), but the technology for economically exploiting this type of heat source is still several years away.

There are several methods by which a geothermal resource can be identified. Drilling, the only certain method, is extremely expensive and therefore is usually done only after the completion of other, considerably less expensive and less certain, surface exploration techniques. The application of these techniques is based largely upon the unique features of a geothermal reservoir. Several geophysical and geochemical exploration techniques and the features each is attempting to identify are presented on the following pages. It is usually necessary to apply a number of techniques in any potential resource area in order to ascertain whether anomalies observed by one method can be substantiated by other techniques.

## GEOPHYSICAL EXPLORATION METHODS

### Gravity

Very precise measurements of the gravity field at the ground surface can identify (1) very dense bodies of rock required for the existence of a long-lived reservoir, (2) areas in which hydrothermal alteration has filled in fractures and pores normally found within the rock strata, or (3) areas in which hydrothermal mineral alteration has removed significant quantities of the denser material originally present.

### Resistivity

The electrical resistivity of subsurface rock strata is strongly affected by the salt content and temperature of the groundwaters circulating through them. Thus rocks saturated with warm saline geothermal fluids have a lower resistivity than those saturated with colder groundwaters.

### Magnetics

Rocks at very high temperatures, or that have been altered by circulating thermal fluids, have a substantially lower magnetic susceptibility than do normal rock strata. These changes are reflected in slight changes in the earth's magnetic field above and around thermal areas.

## GEOCHEMICAL EXPLORATION METHODS

### Groundwater Chemistry

Water at high temperatures tends to dissolve selected minerals out of reservoir rocks and thus thermally altered groundwater has chemistry substantially different from cool groundwaters.

### Trace Element Chemistry

The leakage of geothermal fluids into the near surface tends to create anomalous concentrations of trace and volatile elements (i.e., mercury and radon) at or near the ground surface either by injection or by causing anomalous migration patterns around the areas of leakage.

### Isotope Chemistry

Geothermal fluids often have a unique isotopic character due either to high temperature isotopic exchange between groundwater and reservoir rocks or by the unique character of the minerals and gases dissolved from the reservoir rock (i.e., methane or helium).

### Passive Seismic

Geothermal reservoir rocks (either because of cooling and contraction or a lowering of their mechanical strength) tend to fracture more readily than cold rock strata and thus generate more seismic noise than colder rocks.

### Self Potential

The exact mechanism of the generation of self-potential anomalies (natural voltages at the earth's surface) in Hawaii is not clearly understood. However, self-potential anomalies have been found to be strongly correlated with known thermal anomalies at the Kilauea summit and along the Kilauea east rift.

## GEOCHEMICAL EXPLORATION METHODS

### Temperature/Heat Flow

Geothermal systems often leak high temperature fluids into the near surface environment creating anomalously warm ground or shallow groundwaters. These thermal anomalies can be detected by direct measurement or by airborne infrared imaging.

### III. THE OCCURRENCE OF GEOTHERMAL RESOURCES IN HAWAII

Although geophysical and geochemical exploration work is not yet complete for most survey areas in Hawaii, substantial amounts of data have been acquired on the geothermal potential of Hawaii's volcanic systems. An initial compilation of existing geophysical and geochemical data completed in 1978 (Thomas, et al., 1979) identified approximately twenty areas throughout the state (Figure 2) in which further, more detailed, field investigations were warranted. Geochemical and geophysical exploratory investigations have been completed in some of the identified target areas and are currently underway in several others; a summary of the presently available data from this work is presented below.

#### A. Kauai

The island of Kauai (Figure 3) was formed by one large volcano approximately 3.5 to 5.5 million years ago. Numerous post-erosional volcanic vents, which were active 1 to 2 million years ago, are scattered over the eastern and south-eastern half of the island. Only a few groundwater geochemical anomalies have been identified on Kauai but, even though it is presently believed that the potential for discovering a viable thermal resource on this island is quite low, field surveys in the vicinity of the post-erosional volcanic centers will be necessary to confirm this preliminary conclusion.

#### B. Oahu

The island of Oahu (Figure 4) is made up of two major volcanic edifices: the Waianae shield, formed approximately 2.5 to 3.5 million years ago, and the Koolau shield, which was active from 2.5 million to 20,000 years before present. The latter age includes numerous post-erosional eruptive centers scattered across the southeastern end of Oahu. The preliminary assessment of Oahu's geothermal potential identified six separate areas on the island that warranted further investigation. Although the overall appraisal of the island's potential is generally low due to the relatively great age of both of the major eruptive centers, field investigations conducted in the vicinity of the Waianae caldera in 1978 were much more encouraging than initially expected (Cox, et al., 1979). The geophysical and geochemical techniques applied in the Waianae caldera (Figure 5) included resistivity, groundwater chemistry and temperature, soil mercury and radon, structural and petrological mapping, and

FIGURE 2

POTENTIAL GEOTHERMAL RESOURCE SITES IN HAWAII

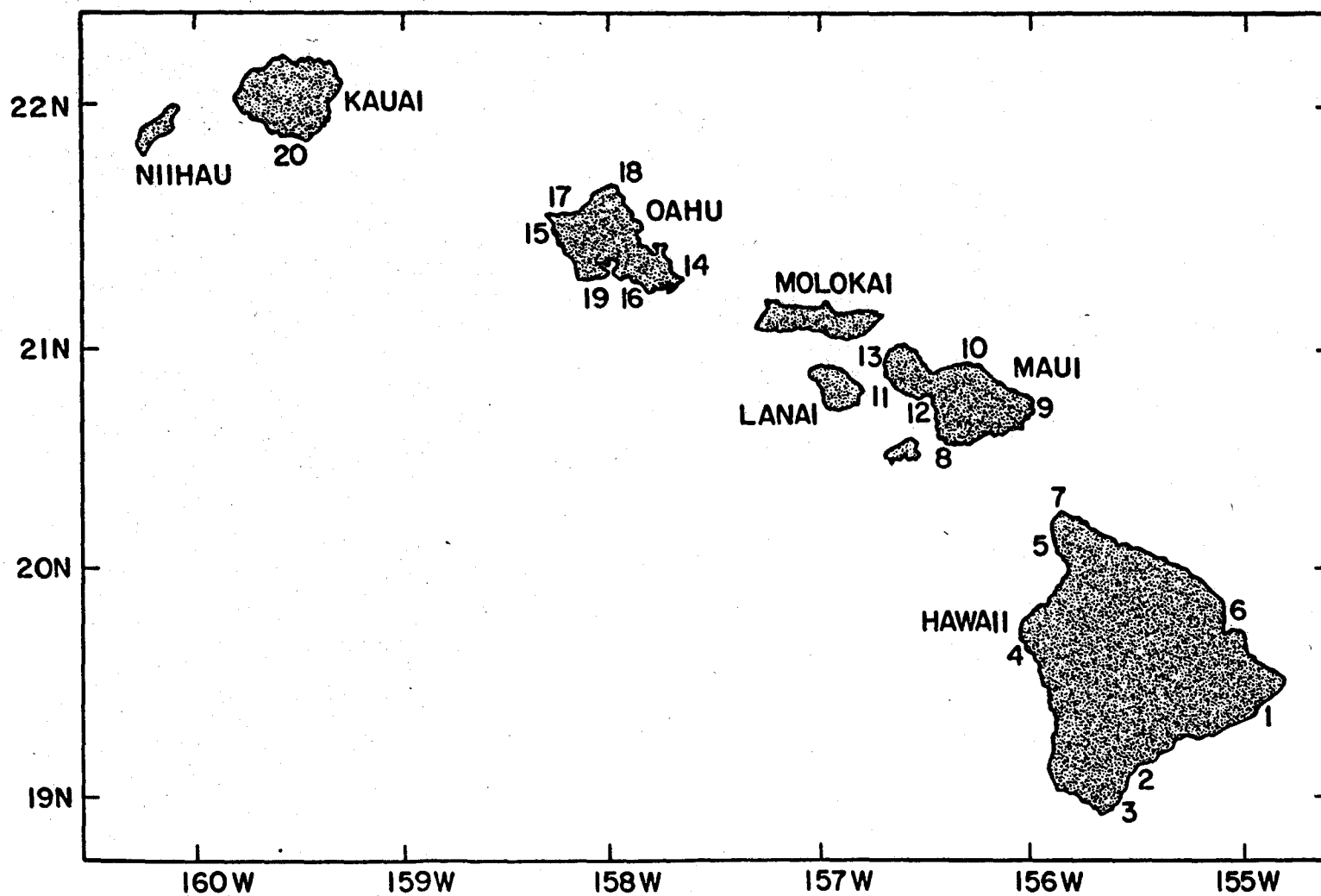


FIGURE 3  
ISLAND OF KAUAI  
SHOWING CALDERA AND RIFT ZONES

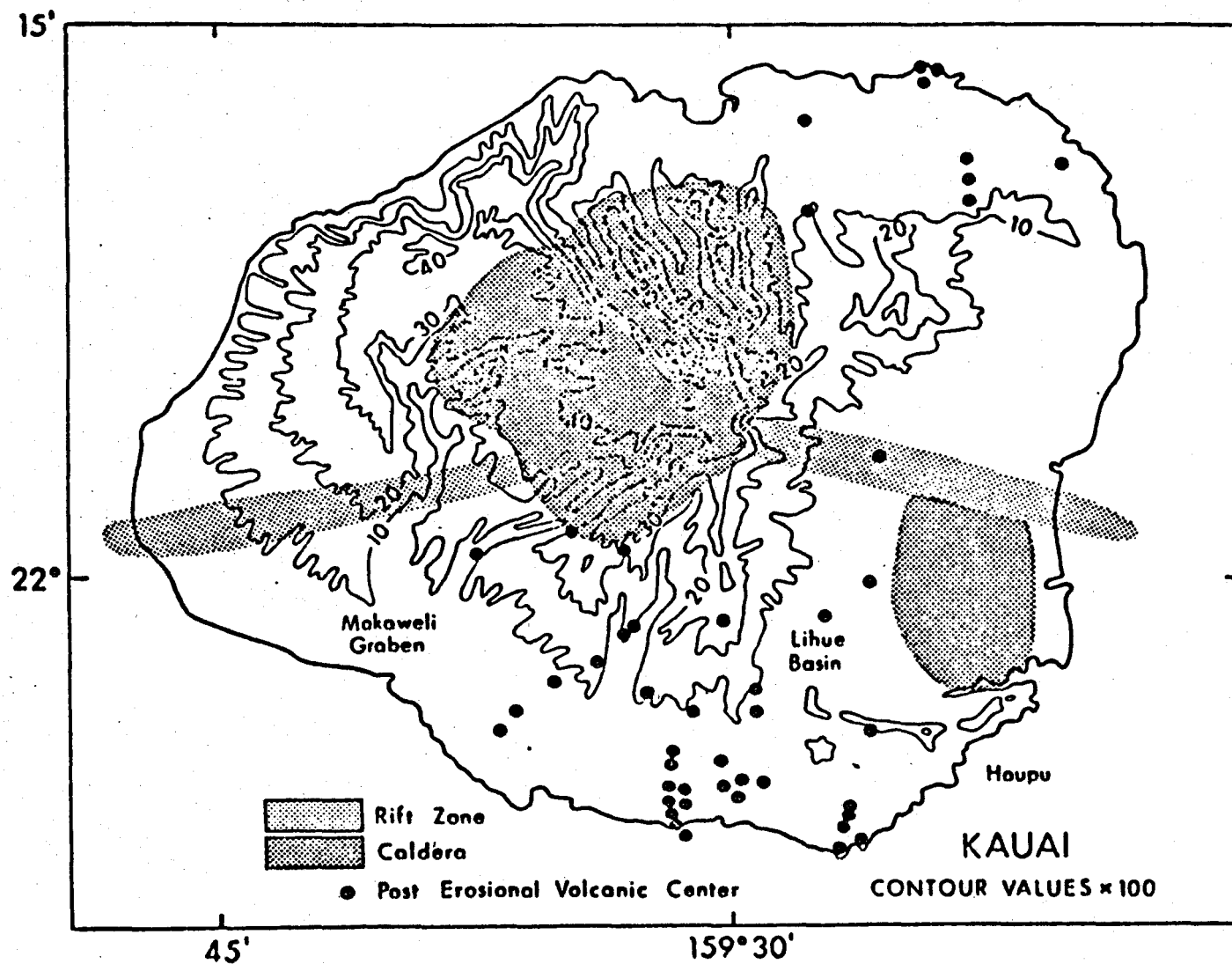




FIGURE 4  
ISLAND OF OAHU  
SHOWING CALDERA AND RIFT ZONES

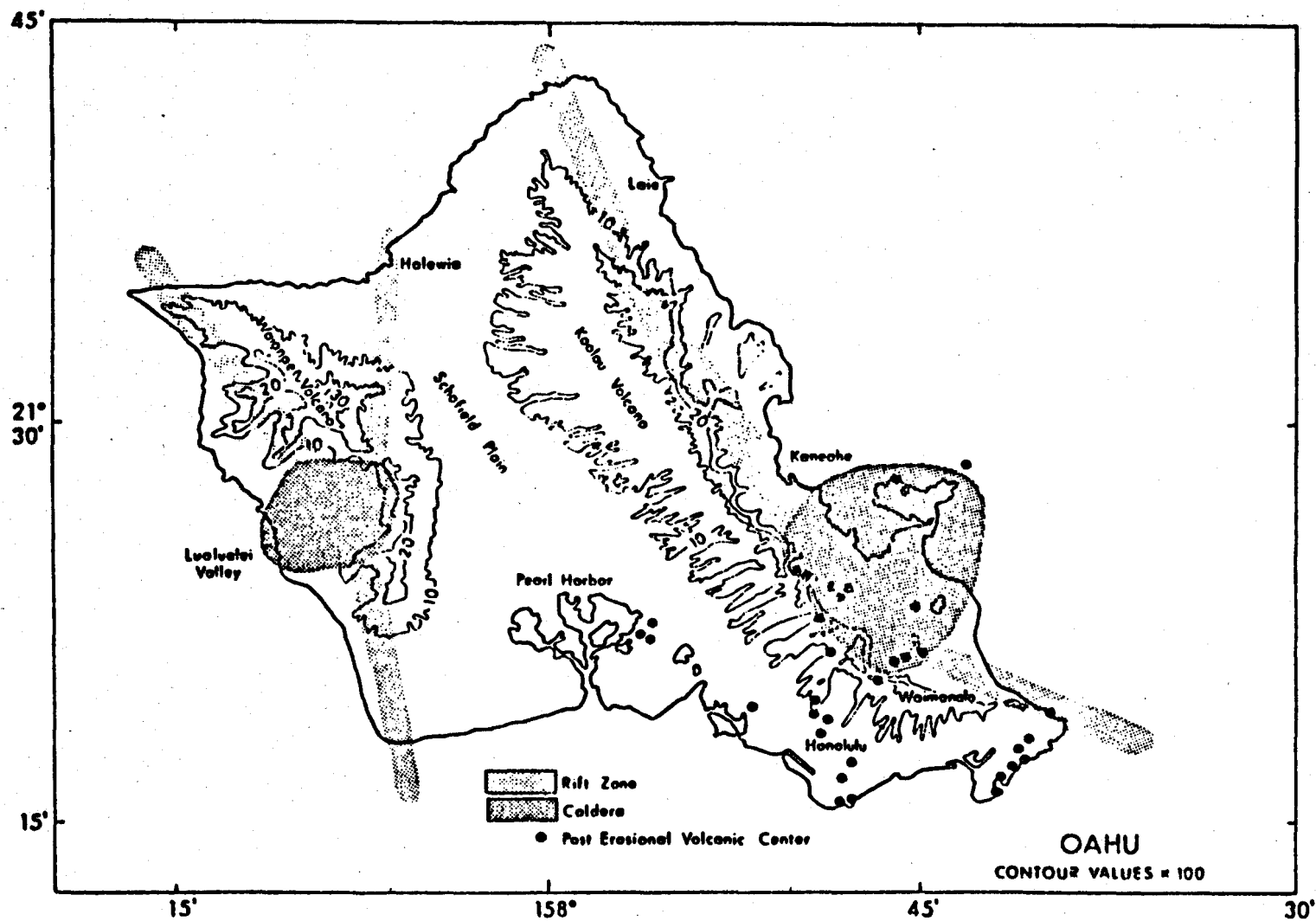
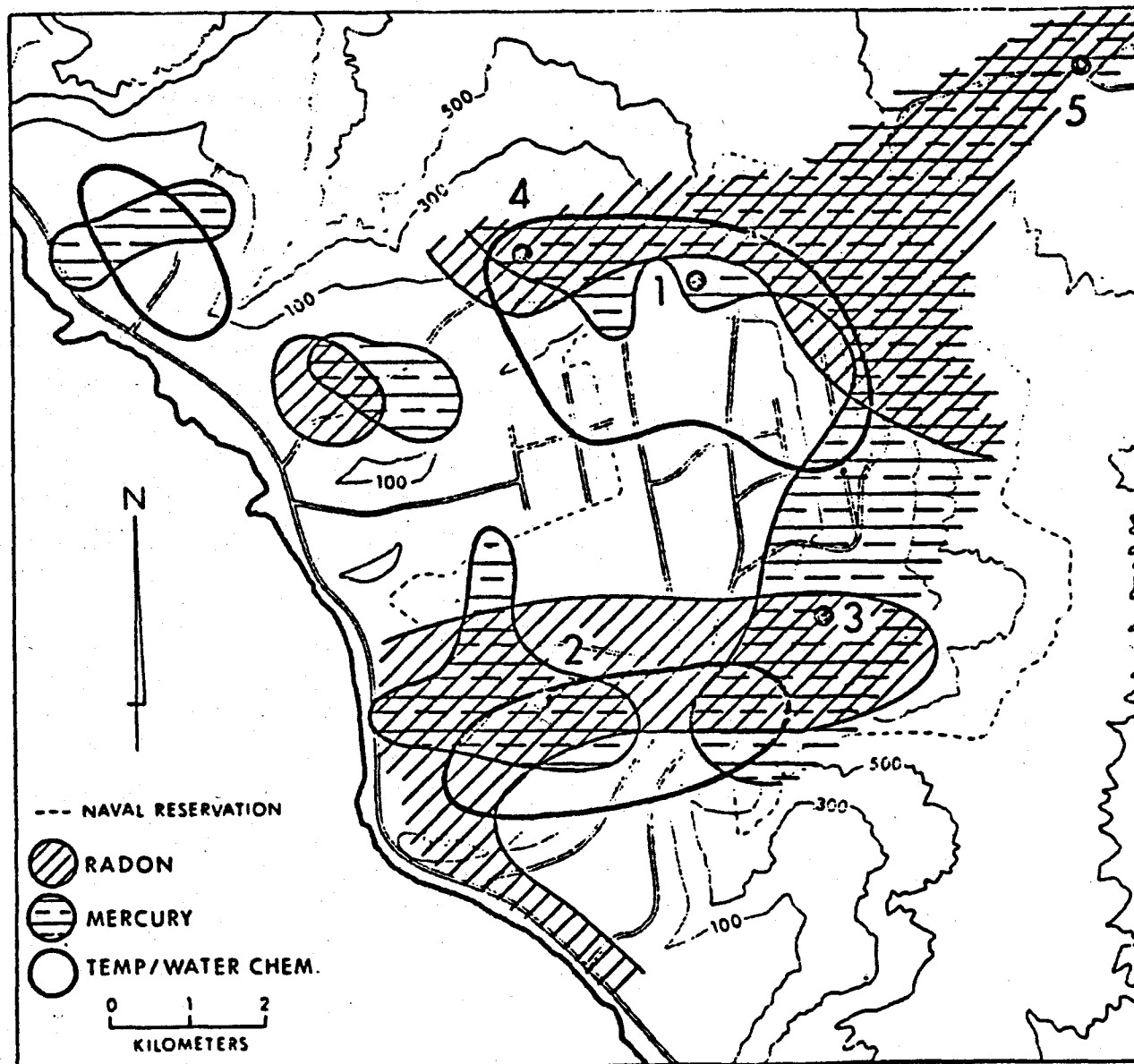


FIGURE 5  
 MAP OF LUALUALEI VALLEY, OAHU  
 SHOWING INDICATORS OF GEOTHERMAL ACTIVITY



alteration mineralogy. The results of these surveys identified several areas around the inferred caldera boundary where anomalous conditions were indicated to be present (Figure 6). Although several alternative explanations for the data are possible, the most reasonable interpretation of the coincident anomalies is that they are arising from at least a low-level heat source within the Waianae caldera system. On the basis of the results obtained, five sites were identified for future exploratory drilling. The U.S. Navy (the present land owner) has taken these recommendations under advisement, but no exploratory drilling is presently planned.

Another identified potential geothermal area on Oahu that has been investigated is the Mokapu Peninsula on the northern edge of the Koolau caldera. Although a detailed geothermal survey was conducted in this area, little evidence of any thermal anomaly was found. Very limited investigations within the Koolau caldera, performed in conjunction with the Mokapu study, identified a few geochemical anomalies that were tentatively attributed to a low-level thermal anomaly. More extensive surveys in this area, as well as in other parts of Oahu, have been forestalled for the present, primarily due to the low probability for finding a high-temperature resource and the high population densities within the more probable development areas.

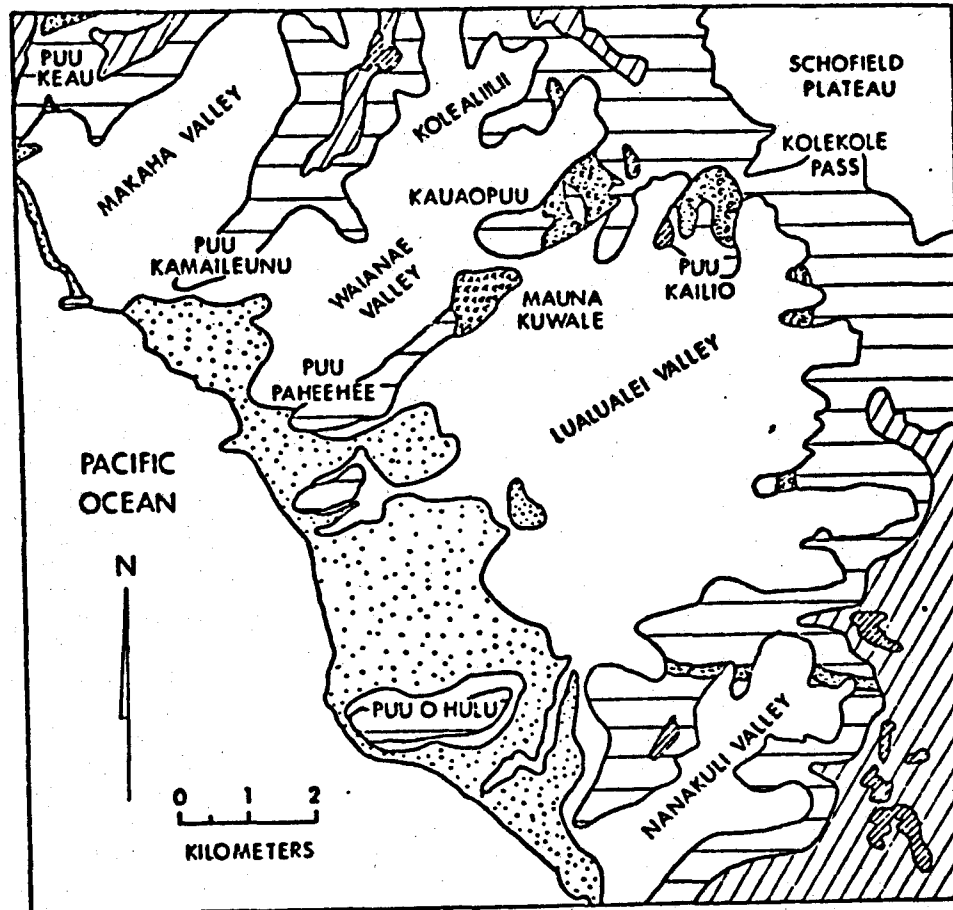
#### C. Maui

The island of Maui (Figure 7) is made up of two major volcanic systems. West Maui is the older and smaller of the two, having an age of at least 1.25 million years to about 600,000; post-erosional activity occurred between about 80,000 and 20,000 years before the present. Haleakala volcano (east Maui) is substantially larger and younger than west Maui; the bulk of the Haleakala shield was built between 1.5 and 0.5 million years ago. Post-erosional volcanism on Haleakala has continued up until the present time, the most recent eruptive activity having occurred in 1790 along the lower southwest rift system.

The preliminary geothermal assessment of Maui identified six areas which were indicated to have some potential for a geothermal resource. These potential areas were identified on the basis of groundwater geochemical and temperature data as well as location and age of most recent volcanism. Three of these areas (Lahaina-Kaanapali, Ukumehame-Olowalu Canyon, and Haleakala northwest rift) are presently under intensive investigation and one other (Haleakala southwest rift) is targeted for field surveys in the near future. The presently available results for the areas being surveyed are as follows:

FIGURE 6

GENERALIZED GEOLOGY MAP OF THE WAIANAE CALDERA  
IN LUALUALEI VALLEY, OAHU



GENERALISED GEOLOGY MAP

- |  |  |                          |                               |
|--|--|--------------------------|-------------------------------|
| Calcareous   | Sedimentary<br>infilling<br>and deposits | Mauna Kuwale<br>Trachyte | Waianae<br>Volcanic<br>Series |
| Non Calcareous<br>(alluvium, colluvium<br>and talus) |  | Cinder Cones             |                               |
|  | Breccia                                  |                          |                               |
|  | Upper Member<br>Lavas                    |                          |                               |
|  | Middle and Lower<br>Member Lavas         |                          |                               |
|  |  |                          |                               |

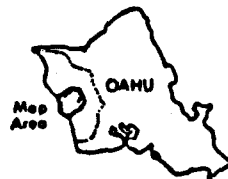
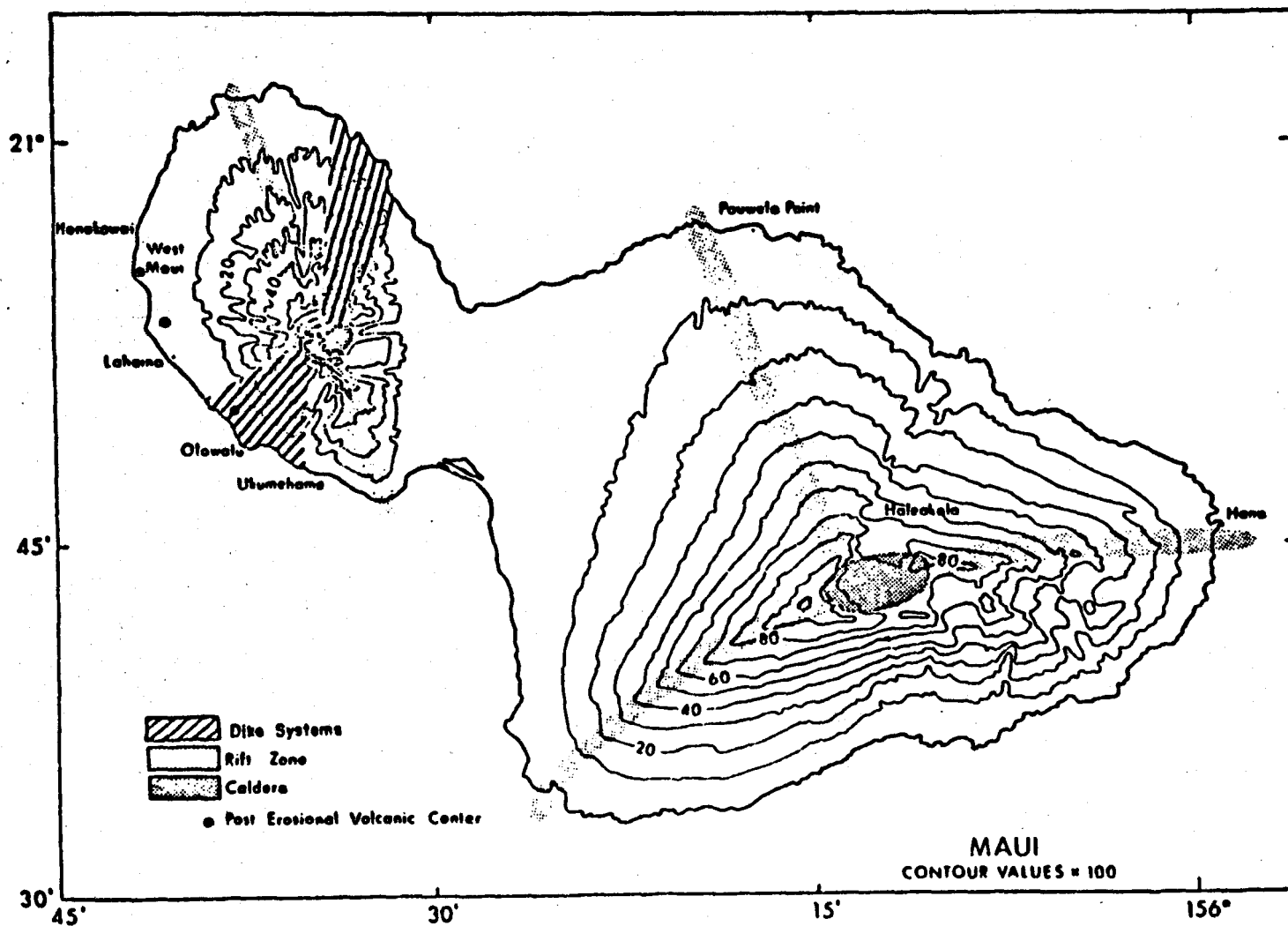


FIGURE 7  
ISLAND OF MAUI  
SHOWING CALDERAS, RIFT ZONES AND DIKE SYSTEMS



1. Lahaina-Kaanapali

Low-level groundwater chemical anomalies have been identified in two locations east of Kaanapali. Roughly coincident with these are anomalous soil mercury and radon concentrations possibly associated with nearby post-erosional eruptive centers. Geophysical surveys in this area, however, have been less encouraging. Resistivity soundings and self-potential surveys both indicate normal or near normal subsurface conditions. Further, more detailed work using other geochemical and geophysical techniques will be necessary before the apparent conflict in the data from this area can be resolved.

2. Olowalu-Ukumehame

Groundwater geochemical and temperature data strongly suggest that a thermal anomaly is present in or near Ukumehame Canyon; one Maui-type water tunnel near the mouth of the canyon has encountered groundwater with a temperature of 33°C (significantly above the expected ambient groundwater temperature), which also has a substantially altered chemical composition. In addition, geophysical surveys conducted in this area have identified apparent resistivity and self-potential anomalies. Although it is not presently possible to uniquely assign a temperature to the source of the inferred geochemical and geophysical anomalies, the estimated resource temperature may range from about 60°C to as high as 170°C. Geophysical surveys are continuing in this area in an effort to further characterize the nature of the observed anomaly.

3. Haleakala northwest rift

Initial data acquired in this area indicated that both groundwater chemistry and temperature anomalies are present. More recent soil mercury and radon data have tended to substantiate the initial anomalous interpretation, but limited geophysical surveys, as well as more recent groundwater studies, suggest that the earlier geochemical evidence may be the result of other non-geothermal processes associated with the northwest rift zone. Further geochemical and geophysical surveys, as well as detailed hydrologic modelling of this area, are underway in an effort to confirm this preliminary evaluation.

Preliminary data acquired for both the east and southwest rift systems on Haleakala indicate that these rift systems may have a greater potential for a geothermal resource than any of the other identified areas on Maui. This evaluation is based primarily on the geological evidence of eruptive activity along these rift systems; a large proportion of the post-erosional activity on east Maui occurred along the southwest and east rift systems of Haleakala. Although relatively little other geophysical and geochemical data are available for these areas, more detailed field surveys for both the east and southwest rift systems are planned for the near future.

#### D. Hawaii

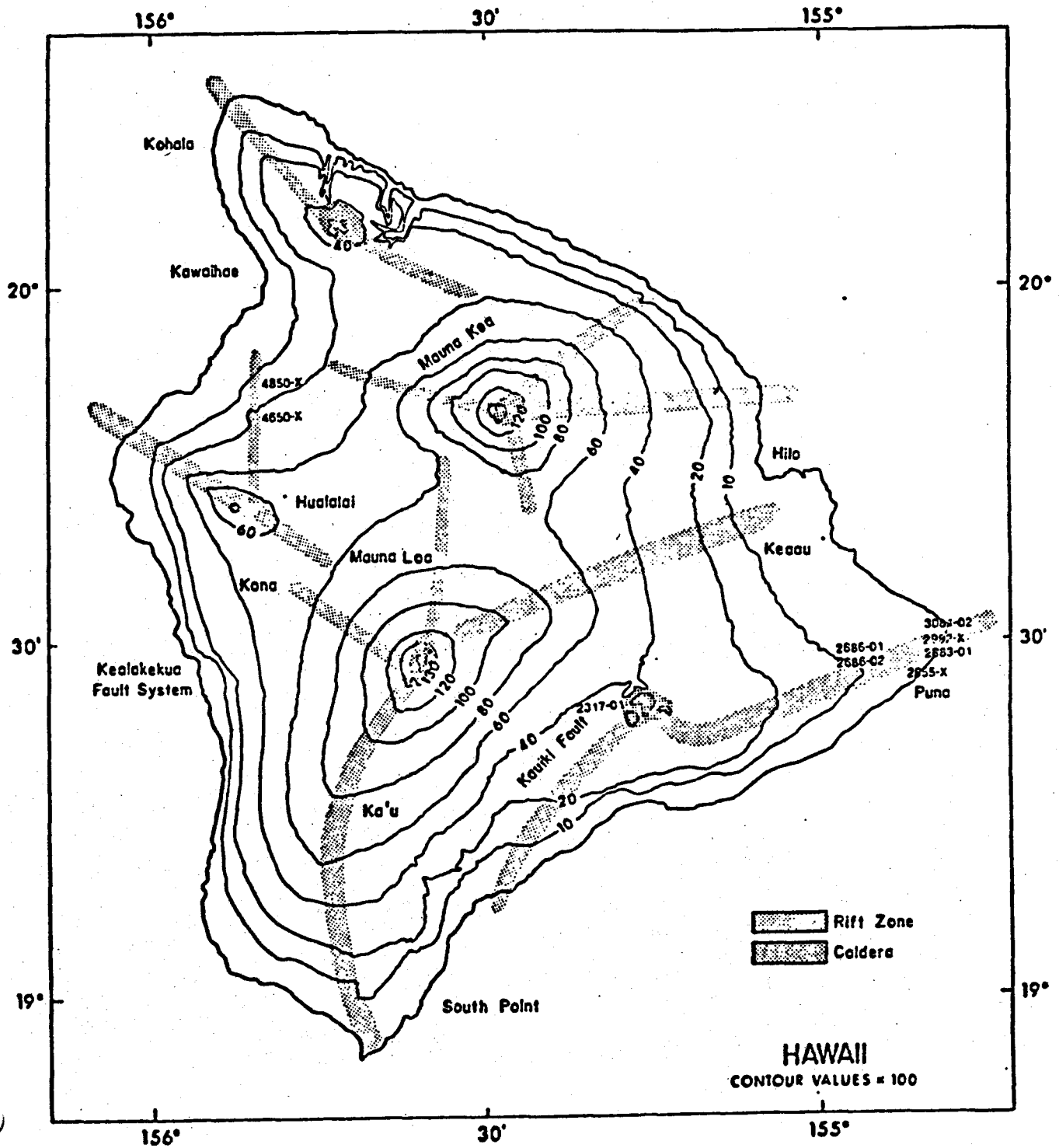
The island of Hawaii (Figure 8) is both the youngest and the largest of the Hawaiian chain. The island is made up of five volcanic systems: Kohala is the oldest and is considered extinct; Mauna Kea is the next oldest and is considered dormant; Hualalai, Mauna Loa and, Kilauea have all had eruptive outbreaks during the last two centuries and thus are considered to be still active. The approximate range of ages for each of these volcanic systems are as follows: Kohala, 1.0 million to approximately 0.080 million years before present; Mauna Kea, 1.0 million years to approximately 3,000 years; Hualalai, 750,000 to 180 years; Mauna Loa, 900,000 years to the present; Kilauea, 100,000 years to the present.

The preliminary survey of the geothermal potential of the Big Island identified seven areas which had some evidence for potentially exploitable geothermal resources. Of these seven areas, one, the Kilauea east rift zone, was studied intensively prior to the siting of the University's HGP-A well; three others, Keaau, Kawaihae, and North Kona, are currently being investigated. Based on the data presently in hand, the appraisal of the geothermal potential of each of these areas is as follows:

##### 1. Kilauea east rift

Geophysical and geochemical data acquired for this area during the Hawaii Geothermal Project's exploration program identified several marked anomalies along the surface trace of the rift zone. The HGP-A well penetrated an extremely hot (358°C) reservoir at a depth of approximately 1,900 meters and has thus proven that a resource is present in the lower Puna area (Chen, et al., 1980). Further, more recent geophysical surveys (Zablocki, 1979)

FIGURE 8  
ISLAND OF HAWAII  
SHOWING CALDERAS AND RIFT ZONES





(Kauahikaua, et al., 1980) suggest that subsurface high temperatures may exist along the entire length of the Kilauea east rift. The results of this work indicate that the entire rift zone could be a geothermal resource area if the other necessary conditions for the formation of a reservoir are present (groundwater, permeability, etc.). The actual extent and long-term viability of the resource, however, can only be proven by further and much more extensive exploratory drilling and long-term production. Presently available estimates of the geothermal potential of this east rift range from 100 MWe centuries (Suyenaga, et al., 1978) to more than 3,000 MWe centuries (Helsley, 1980).

2. Keaau

Initial groundwater chemistry data collected near Keaau indicated that thermally altered groundwater, possibly associated with the Mauna Loa east rift, might be present in this area. Subsequent, more extensive geophysical and geochemical field surveys conducted around Keaau indicate that the anomalous groundwater chemistry may be the result of other, non-thermal, processes. The presently available data on Keaau strongly suggest that no thermal resource is present in this area.

3. Kawaihae

This area was originally identified as a potential geothermal area on the basis of groundwater chemistry and temperature data from wells to the east of Kawaihae Bay. More recent surveys have confirmed the original data and have tentatively located a possible source of the thermal anomaly; geophysical surveys identified a highly resistive layer at a depth of a few hundred meters below sea level that is interpreted to be an intrusive body associated with Puu Kawaiwai, a cinder cone associated with the Kohala post-erosional volcanic series. More extensive geophysical and geochemical surveys are presently underway in this area in an effort to both confirm this interpretation and to more fully characterize the inferred resource.

#### 4. North Kona-Hualalai

Preliminary surveys of North Kona district identified both water-chemistry and thermal-infrared anomalies along the coastal areas. More extensive trace-element geochemical surveys near Kailua-Kona have also identified apparent anomalies thought to be associated with Hualalai volcano. Although geophysical exploration in the North Kona area has been severely hampered by cultural interferences (power lines, buried pipes, etc.), detailed geophysical surveys conducted to the north of Kailua, near the Hualalai summit, have indicated that a conductive zone is present a few hundred meters below the surface. This has tentatively been identified as a layer of warm, and possibly geothermally altered, groundwater. In addition, a second subsurface low-resistivity zone has been identified along the lower northwest rift of Hualalai near the cinder cone Puu Mau. Although both of these areas are thought to have a potential thermal anomaly present, considerably more exploration work is required to confirm their existence.

Relatively little recent data are available for the other areas on Hawaii that may have some potential for a thermal resource: South Point, Kilauea southwest rift, Mauna Kea, and Kohala. Both South Point and the Kilauea southwest rift are thought to have a higher probability for a resource since both have been volcanically active during recorded history (Mauna Loa in 1890 and Kilauea in 1920), and thermal manifestations have been reported along both rifts (Macdonald and Abbott, 1970). However, few detailed geophysical surveys have been conducted over either area and virtually no geochemical data are available for soil or groundwater on either rift system. Thus, even though the geothermal potential in both areas is considered probable geologically, it is not yet possible to provide a more precise estimate of their potential.

Both Mauna Kea and Kohala volcanoes (compared with Waianae or west Maui) are relatively young and, on this basis, may be considered to have some geothermal potential. However, until more geophysical and geochemical studies are conducted on these volcanic systems, no valid appraisal of their potential can be made.

In summary, it is apparent that several of the volcanic systems within the Hawaiian island chain have some evidence for the existence of a geothermal resource. Although only one of these areas can be considered to have a proven geothermal reservoir (the Kilauea east rift zone) recent field surveys have provided data strongly suggestive of a geothermal anomaly in several others. Evaluation and characterization of these identified anomalies are currently underway, and exploration in other potential geothermal areas is continuing. The production capacity of one proven geothermal reservoir in Hawaii, the Kilauea lower east rift zone, has been initially estimated to be of the order of 100 to 3,000 megawatt centuries, but the actual production capacity of this area, as well as that of all other identified geothermal resources in Hawaii, will be determined only by much more extensive exploratory drilling and production from each individual reservoir.

#### IV. OVERVIEW OF GEOTHERMAL MARKETS

##### A. Introduction

The development of geothermal energy will be an important step for the State of Hawaii toward attaining the goal of energy self-sufficiency. At present, Hawaii has a 90 percent dependency upon oil for its energy requirements. Because of the world situation, geothermal energy may prove to be a more reliable source of energy than imported oil. The benefit to the state would be a reduction in the outflow of dollars used to purchase energy from oil.

Geothermal energy would be marketed in one of two forms:

1. Electricity, or
2. Direct heat (steam or hot water).

The marketing of geothermal energy as electricity has the advantage of an existing island-wide transmission and distribution system on each island, providing a widespread market for the energy. Further, the Federal PURPA (Public Utility Regulatory Policies Act) regulations require utilities to purchase electricity, up to the utility's capacity to handle it, offered for sale by small power producers. The price paid for the power must reflect the "avoided cost" of the utility, that is, the cost which the utility would incur if it had to generate the same amount of electricity with its own equipment. Although this formula will have the effect of coupling the prices of alternate energy sources to the price of petroleum energy, PURPA will have a major positive impact on the marketing of geothermal energy in Hawaii.

Large industrial users of electricity could utilize the power directly from a wellhead generator if the industry is located sufficiently near the well. Presently, there are a limited number of potential direct-heat users of geothermal energy. Many of the industries which use substantial amounts of process heat have a number of energy options open to them, thus geothermal steam will be competing with alternate fuels, like ethanol, methane, or liquified coal in the energy market. Smaller heat users are less likely to have the means to relocate to a geothermal area. Therefore the major marketing opportunities for geothermal steam in the near future will be in industries new to Hawaii. Geothermal energy, either as heat or

electricity, cannot be easily stored for any significant length of time on a large scale. Thus, the "shelf life" of the product is for all practical purposes zero. The nature of the resource is also such that the demand on the geothermal well must be relatively constant. The geothermal well cannot tolerate frequent shutdowns and startups -- nor wide variations in output -- without risking mechanical damage due to the thermal cycling. Thus, in order to minimize the dumping of excess steam, users with relatively constant energy requirements, or a large number of intermittent energy users, should be sought.

Marketing of geothermal energy as steam or hot water ("direct heat applications") is complex, and a number of barriers must be overcome before it can become competitive. Historically, in Hawaii and elsewhere, the marketing pattern for energy has been the distribution of the fuel or power to the energy user, whatever his location. While energy users tend to cluster near major energy distribution centers like Honolulu, on a more local scale the location of an industry has not been dictated by energy requirements. Within reasonable limits, petroleum fuels and electricity are distributed to all points with little variation in price. A major reason for this is the presence of well-developed infrastructures for the distribution of these energy sources. Energy users have grown accustomed to the great conveniences inherent in the existing system. Energy is delivered to them, and it can be easily stored as a hedge against demand fluctuations and supply interruptions. Marketing geothermal steam or hot water, however, will involve convincing existing energy users to relocate their plants closer to the geothermal well, and potential new industries to site their facilities there. This will involve greater capital expenditures on the part of the potential geothermal energy users, and possibly higher transportation costs if the geothermal resource is in a location remote from major transportation centers and markets.

Further, geothermal energy development is capital-intensive, and must take place on a scale large enough to make it cost-effective. A single geothermal well produces on the order of one trillion BTU's per year, equivalent to about one-half the energy requirements of a sugar factory. Exploration, drilling, and distribution costs remain relatively constant if the size of the well is reduced. Therefore, enough users must be attracted to utilize this amount of energy. Thus, the industrial park concept of geothermal energy distribution has been advanced to accomplish the complete utilization of the energy. Generally, the

marketing of geothermal energy is no different from the marketing of any other products. The consumer must perceive some advantage in utilizing the product. For most users the advantage sought would be economic. While the bottom line of the income statement is important to businesses, other advantages such as a stable energy supply, being a pioneer in the field, etc. may prove to be selling points also.

#### B. Electricity Production

One use for the geothermal resources would be for electricity generation. Electric utilities currently consume about 28 percent of the energy within the state. Converting the geothermal energy into electricity would solve some of the problems related to the use of geothermal energy. Electricity has wide usage, is easily marketed, and the demand for electricity has been continually growing over the past decade. Generation of electricity would be an intensive and continuous use of the geothermal resource. The statewide consumption of electricity is over 6 million megawatt hours per year.

The electricity generated in the state is primarily from oil. All of the utilities are heavily dependent upon oil as a source of energy, and nearly one half of the cost of electricity is due to the cost of oil. Utilization of geothermal energy to generate electricity would also avoid the problem of transporting the resource, since electricity could be generated at the site of the wellhead. The existing infrastructure for distributing electricity can continue to be utilized. The use of the geothermal resource to produce electricity will be hindered by several conditions. Generation of electricity requires a high-temperature resource that is unlikely to be found outside the islands of Hawaii and Maui, but the major demands for electricity are not found on either island. The development of the full market potential for electricity would necessitate a submarine cable to transmit the electricity to the major market on Oahu. Without such a transmission system generation of electricity from geothermal resources on the Big Island and Maui is hampered by the size of the local markets. It also faces competition from biomass-generated electricity; four sugar companies on the Big Island and two on Maui sell electricity generated from the burning of bagasse, the residue from cane processing. Other sugar companies on both islands are also considering selling electricity to the utilities.

## C. Direct Heat Applications for Geothermal Heat

### 1. Tourism/Spa

The visitor industry is the leading source of income in the state. In 1976 visitors spent \$2.2 billion in Hawaii. Defense expenditures, the second largest source of external income, were \$1.2 billion for the same period (State of Hawaii Data Book, 1979). The visitor trade may provide a market for the geothermal resources in the state in the form of spas or for heating and cooling in visitor complexes.

The utilization of geothermally heated water in the visitor industry is not new. Spas in Europe, Japan, the United States, the USSR and other countries have been attracting visitors for years. Some European spas have been attracting visitors since the Roman conquest. Spas in Hawaii would enable the visitor industry to tap a different segment of the visitor market, thereby expanding the total market pool of visitors to Hawaii.

Several areas identified as having geothermal potential are also identified by the state as current or future tourist destinations. On Maui the Lahaina/Kaanapali and Kihei/Wailea areas are the island's largest tourist destinations, with 62 and 32 percent, respectively, of the total room inventory. On the Big Island, Kailua-Kona is well established as a visitor attraction, and the Kawaihae area is being rapidly developed. Makaha and West Beach on Oahu have also been recognized as tourist destinations. Many spas with geothermal resources use the heated fluids not only for bathing but for drinking. Claims for the properties of geothermally heated waters range from merely refreshing to definitely curative. In Hawaii, the potability of geothermal water would depend upon its chemical content. A low-temperature geothermal resource (about 70°-110°F) is usually sufficient for bathing waters; other spa applications may require a higher-temperature resource, depending upon the specific usage. The spa should be more than heated water. Resort developers caution that the occurrence of geothermally heated water would merely be another amenity. Much more would have to be offered to make a spa attractive. Many spas throughout the world offer a whole regimen of activities, usually health or beauty related (Wilkens, 1976).

The use of geothermal energy in the tourist industry need not be limited to the spa concept. The geothermal resource can be used to meet hot-water and/or space-cooling needs. Both of these uses require higher temperatures than bathing or drinking. For heating requirements a resource temperature upwards of 150°F would be required; at least 250°F is needed for space cooling. Perhaps the best-known use of geothermal energy for air conditioning is the International Hotel in Rotorua, New Zealand, which employs a resource of 270°F in lithium bromide absorption cooling unit. The same geothermal well also provides the hotel's hot tap water and its space-heating requirements in winter (Armstead, 1978). Geothermally powered space cooling is also used in the Soviet Union.

It would be difficult to determine the hot water needs for a hotel without information on the amenities to be included, restaurants, laundry facilities, heated swimming pools, etc., however it is estimated that each hotel unit would require an average of about 30 gallons per day of 120°F water. A typical clustered complex of 1,200 - 3,000 units would require about 20-50 million BTU's per day for heating hot water for the rooms alone.

## 2. Agriculture

Agriculture, one of the leading industries in the state, is dominated by sugar and pineapple production. The sale of agricultural products totaled \$439.1 million in 1979. Of this amount, \$217.6 million was attributed to sugar; pineapple contributed \$69.5 million (Hawaiian Agriculture Reporting Service, 1979).

The processing of sugar cane is heat intensive and would be a good candidate for the use of geothermal energy. There are several sugar-processing operations in areas with geothermal potential. The Puna Sugar Company and Ka'u Sugar Company are close to geothermal resources on the Big Island and Hawaiian Commercial and Sugar (Paia) and Pioneer Mill on Maui are also near potential resources.



The Puna Sugar Company has conducted a study on the feasibility of utilizing the geothermal energy from the resource at Puna in its factory operations. According to the study, the major barrier to the use of geothermal energy in the sugar industry is economic; if the resource were close enough and of a high enough temperature there would be few technical problems. Typical requirements for a mill are 160,000 - 220,000 pounds per hour of 250°F 15 psi steam. The processing of a pound of sugar consumes about 5,800 BTU's. Most sugar mills operate 24 hours a day for about 10 months of the year.

All the sugar processors noted above utilize bagasse to heat their boilers for process-steam requirements. Puna Sugar Company and HC&S sell electricity, generated by the excess bagasse, to the utilities. Ka'u Sugar and Pioneer Mill do not currently sell significant quantities of electricity. If the sugar processors were to utilize geothermal energy the excess steam could be used to produce more electricity for sale. Utilization of the geothermal energy would also reduce the use of oil by sugar producers. All of the processors use oil in the boilers to supplement bagasse.

Poultry farming also offers possibilities for the use of geothermal energy. Over 85 percent of the poultry products produced in the state come from Oahu. Of the 26 poultry farms on Oahu, about one-third are in the Lualualei area, and these farms produce about two-thirds of the poultry products on Oahu. Poultry production can utilize lower-temperature resources. On the Izu peninsula in Japan, heated water (100°C) is circulated under the floor of poultry operations to maintain a constant temperature.

### 3. Food Processing: Fruits and Vegetables

The use of geothermal energy in the processing of fruits and vegetables is another possible market in Hawaii's agricultural environment. The food processing industry can utilize a moderate temperature resource and the resource can be cascaded efficiently through the processes of cooking, blanching, dilution of stocks, wash water, etc. Energy requirements run about 900,000 BTU's per 1,000 pounds of canned fruit or vegetables.

The largest food-processing operation in the state is the canning of pineapples, but there are no pineapple canneries close to identified geothermal resources. The processing of other foods such as macadamia nuts, coffee, guava, papaya, and bananas hold possibilities for the use of geothermal energy.

Macadamia nuts and coffee are currently processed in the state, primarily on the Big Island. Papayas and bananas are usually sold fresh. Only about 11 percent of the papayas are currently processed. The processing of papayas and bananas would utilize off-grade fruits that are, for the most part, wasted. Guavas are also being processed into purees and preserves.

Current coffee operations require heat for drying coffee beans to take them from the fresh-cherry stage to the parchment stage. The operation in Kona requires about a 160°F for the drying process. Roasting requires temperatures of about 540°F, well beyond the range of any geothermal resource. The macadamia operations in Kona also require heat in the drying process. The Kona operation husks, shells, and dries the nuts. The heat required for drying is also 160°F. At present, this operation uses oil to fire the boiler. An operation in Keaau takes the nuts from the raw stage to the finished product ready for the market. In addition to fuel oil, the husks and shells of the nuts are used to fire the boilers for process-heat requirements. The operation is outside a 10-mile radius of the geothermal resource at Puna.

#### 4. Aquaculture

The importance of aquaculture as a means of providing cheap, plentiful protein is gaining recognition throughout the world. Hawaii's climate is well suited to year-round aquaculture activities, and aquaculture development is expanding in the state. The number and variety of farms are increasing, and research is continuing on the various types of marine life that can be successfully cultivated. The market for aquaculture products looks favorable. In the United States, seafood consumption rose by about 22 percent between 1969 and 1976. Of the 2.7 billion pounds of seafood consumed in the United States in 1976, 60 percent was imported. Trends within the United States are expected to increase the consumption of seafoods even more, and Hawaii's central location would make the Far East market quite accessible. In addition, seafood products could be marketed in Europe.

So far, prawns have been the focus of most of the aquaculture activities in the state. This year, the prawn farms in Hawaii are expected to produce about 258,000 pounds, hardly a dent in the estimated 1,000 million pounds of shrimp and prawns that will be consumed in the United States alone. This projected yield will not even fill the local hotel and restaurant demand, conservatively assessed to be 400,000 - 600,000 pounds.

Oysters and different types of fishes are also being produced on farms in Hawaii, and research is being conducted on seaweeds and various types of fishes and shellfishes.

Aquaculture activities can take advantage of the lower-temperature resources. Heating requirements for aquaculture operations are between 68°F and 90°F; geothermal fluids can be utilized to maintain the optimal growing temperatures. Currently, only one operation in Hawaii utilizes heated water. Mr. Terry Astro, of Astro Marina, Inc., uses the effluent waters from a power plant to maintain a temperature of 90°F for his tilapia operations on Kauai. The elevated temperature is said to increase growth by about 12 percent per day. Mr. Astro is planning on three growth cycles per year and an ultimate harvest of about 1,000 pounds per day from 1.5 acres. The system's water-flow rate fluctuates but the average flow rate is about 500 gallons per minute. A planned catfish farm on Maui will also be located close to a utility, but the operation will not be able to use the effluent discharge because of the salinity of the discharged fluids.

A study conducted by EG&G in the Raft River area of Idaho observed that fish grown in heated geothermal waters did seem to have a higher growth rate. Since the study was to determine the effects of geothermal water on the edibility of fish, conclusive results on the growth effect of heated water were not drawn. The study did conclude that the mineral content of the geothermal fluid did not affect the growth or edibility of the fish raised in it. Experiments will have to be conducted on the fluids found at the individual geothermal sites in Hawaii to determine the feasibility of utilizing the fluids directly as the culture medium. Some minerals are detrimental to the growth of shellfish, and mollusks are known to retain toxins that may affect their edibility. If the geothermal fluids can be used as the medium the complementary aspects of aquaculture and geothermal activities would be enhanced.

South Kohala, close to the potential resource at Kawaihae, and Kihei, close to La Perouse Bay, are developing aquaculture projects. These are the only aquaculture projects close to potential geothermal resources. The State of Hawaii has identified areas suitable for aquaculture development. The bulk of the 135,000 acres identified as primary aquaculture-development lands are on Oahu, followed by Kauai and Maui. The Big Island has the largest amount of identified secondary lands. Areas with geothermal potential also identified as having primary aquaculture lands are Lahaina, Olowalu, Paia and Lualualei.

The location of aquaculture lands close to potential geothermal resources increases the attraction of aquaculture as a market for the use of geothermal energy. Existing or new developers could locate, relocate, or expand their operations to the area.

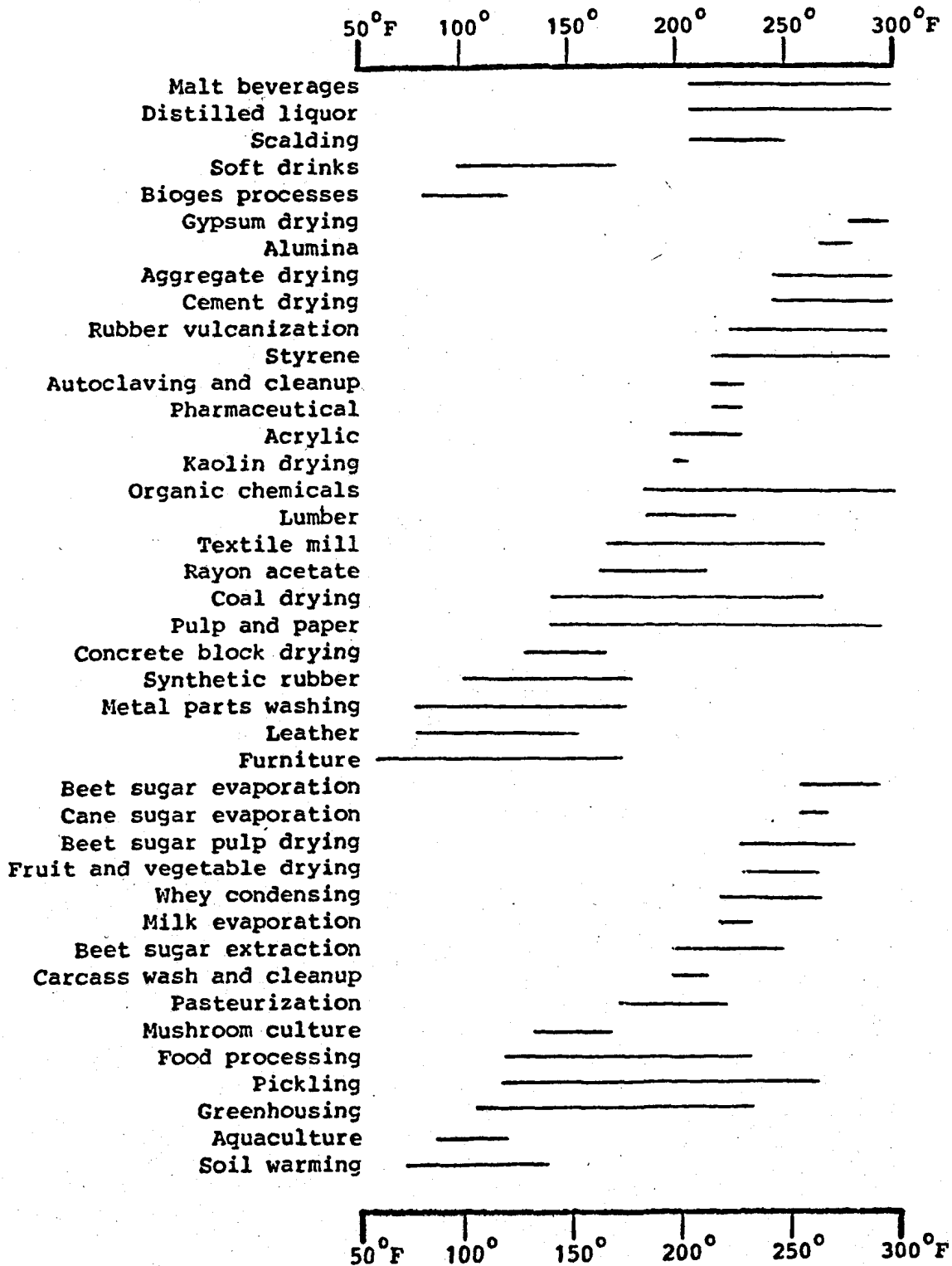
#### 5. Other Uses

There are many other uses for geothermal energy that may not be energy intensive. Existing industries that are not energy intensive should not be totally disregarded. Although their energy usage cannot justify primary use of the geothermal resource, they may be able to use the cascaded energy from the primary user. Multiple uses of the direct heat may result in a more efficient use of the energy and may help to spread some of the costs (see Table 2).

Industries not currently existing in Hawaii may find energy from the geothermal resources attractive. This would encourage the development of the geothermal resources. Local needs may also provide a market for the geothermal energy. Desalination of water, although not being done commercially in the state, may be an application for the energy. Water-shortage problems may make the use of geothermal energy in the desalination process a feasible market. Desalination is a heat-intensive process that has moderate heat requirements, 120°C. This temperature may be found on Oahu where the need seems to be most critical. Desalination may also provide water to irrigate fields in the drier North Kona, South Point, and Kawaihae areas. In addition, geothermal energy could be utilized for pumping water for field irrigation. This could open up agricultural possibilities in the drier regions that have geothermal potential.

TABLE 2

## POTENTIAL DIRECT HEAT APPLICATIONS



Geothermal energy in the pumping of water could also be used in hydroelectric pumped storage systems. Applications for geothermal energy may result from other uses of the energy. For example, if geothermal energy were used in aquaculture development, processing the products could also use the energy. Seaweed drying could utilize the geothermal resource, as could fish processing. Absorption cooling could provide refrigeration needs. If geothermal waters are felt to have a curative property, a bottling industry like those of some European spas may result.

Industries already established in the state may want to take advantage of the geothermal energy. Existing operations may wish to relocate or expand, or new entrants may appear. One example is the lumber industry. The lumber industry in the state is rather limited and there are no milling operations close to potential geothermal sites. If the economics are favorable enough, the industry does have the possibility of expanding into areas close to geothermal resources. One example is in the Puna district. Campbell Estate trustees are looking into developing the timber resources on their lands in Puna. A dairy in Waianae, Toledo-Twin Pine Dairy, is looking into the feasibility of entering into the milk processing field now dominated by Foremost and Meadow Gold dairies. Milk processing with geothermal energy is being done at Klamath Falls, Oregon (Belcastro, 1978). Geothermal energy for milk processing may provide the economic edge that could encourage new milk processors to enter the field or existing ones to relocate plants.

## V. POTENTIAL MARKETS IN THE IDENTIFIED GEOTHERMAL AREAS

### A. Puna District, Big Island

The Puna area has the only clearly defined geothermal resource in the state. Even with this distinction much more information about the resource is needed before full scale development can begin. Exploration of the resource by private industry has begun. Approval has been granted to two separate developers for the drilling of exploratory wells. If the resources at Puna prove the potential of the demonstration well, the generation of electricity would probably be the first use of the high-temperature resource.

Possibilities for direct heat uses are already being considered. Puna Sugar Company, a division of Amfac, conducted a feasibility study of utilizing the geothermal energy in the milling of sugar at the factory in Keaau (Humme, et al., 1979). The study showed no technical barriers to the use of geothermal energy in the processing of sugar cane; the problems encountered were economic. One of the major stumbling blocks was the cost of piping the resource from the wellhead to the factory. The transmission of the fluid over fourteen miles detracted greatly from the economic feasibility of the project. The study pointed out that governmental participation to supplement private financing of the project would have enhanced the viability of the project. Government ownership and operation of an energy corridor between the Kilauea east rift zone and the Keaau factory would have reduced capital requirements by more than one half. The use of geothermal energy by Puna Sugar Company cannot be ruled out completely. If resources were found closer to the milling site or if other geothermal steam users were to locate in Keaau, the transmission costs could be reduced or spread over more users to make the project more than marginally economical.

Currently, Puna Sugar has a contract to provide electricity to the utility on a firm basis. The company co-generates electricity and process steam for the sugar operations. The energy is generated by the burning of bagasse; oil is used when the bagasse is unavailable. The use of geothermal energy to replace bagasse would enable the plantation to increase its electricity sale to the utility and decrease the amount of oil used.

Hawaiian Dredging and Construction, a Dillingham company, has conducted a study on the feasibility of using the geothermal resource in an industrial park. The idea of developing a park that would gather commercial users of geothermal energy into one area is not a new one. One study (Hornburg, 1978) contends that only by the concurrent development of industrial uses of geothermal resource can other nonelectric uses for geothermal energy be advanced. Also gathering the users of the energy would result in the maximum utilization of the energy. The final report of the study done by Hawaiian Dredging has not yet been published, but among the best candidates selected for the park are an ethanol producing plant and a papaya processing plant (Hawaiian Dredging and Construction, 1980). Both fit well into the general activities of the Puna area. The ethanol plant, being considered as the anchor industry for the park, would convert lignocellulosic materials, specifically bagasse and woody fiber, into alcohol. The raw materials are available close to the proposed plant, although perhaps not in sufficient quantities. Thus there will be a need to transport some materials from other areas on the island.

Bagasse is available from the Puna Sugar Company and there is woody fiber available in the Puna area, near Kalapana. The ethanol plant being considered would produce 20,000 gallons of ethanol per day and require over 300 tons of feedstock per day. The energy-intensive process would require 50,000 - 100,000 BTU's of geothermal energy to produce a gallon of ethanol. The process requires heat up to about 225°C. The temperature and flow rate discovered at the HGP-A well are sufficient for the requirements of the plant. An ethanol plant along the lines of the one being considered would also serve to stimulate the development of the supporting industries, including timber production and logging, energy-tree farming, and perhaps even bagasse production. These are all quite compatible with activities currently conducted in Puna.

Gasoline consumption in the state has been steadily rising. Current annual consumption of gasoline is about 325 million gallons. If ethanol were used in a 10 percent concentration to produce a gasohol mixture, the market potential for ethanol would be 32.5 million gallons per year. This market could support a 90,000-gallon-per-day ethanol industry. The limitation on fulfilling the demand would be the availability of the feedstock. About 25,000 acres of land to produce the feedstock -- trees or other forms of biomass -- would be required to meet the demands of producing 90,000 gallons of ethanol per day.



The Department of Planning and Economic Development has examined the marketing of gasohol in Hawaii in a 1980 report. The study perceived the unleaded gasoline consumption of Hawaii as the immediate market for ethanol blending. Unleaded gasoline comprises about one-third of the gasoline consumption in Hawaii, or about 300,000 gallons per day. It was noted that the two major oil companies in Hawaii, Shell and Chevron, are not currently taking the initiative to produce, blend, distribute, or market gasohol. However, they appear willing to market gasohol if and when the ethanol becomes widely available in the state and if problems associated with the storage and handling of the fuel are resolved satisfactorily. Pacific Resources, Inc. is presently test marketing gasohol at ARCO stations in Honolulu. Both Pacific Resources, Inc. and the State Department of Planning and Economic Development believe that ethanol is the fuel of the near future, and that the demonstrated superior performance of gasohol over unleaded gasoline will result in consumer acceptance of the fuel.

A price of about \$2.00 per gallon for gasoline would make the ethanol production for gasohol competitive with gasoline. Gasoline is currently retailed at about \$1.50 per gallon and the \$2.00 per gallon price does not seem to be far from becoming a reality. Gasohol has been successfully marketed on the mainland and is popular with motorists in spite of its slightly higher price.

While an ethanol plant is currently being considered for the Big Island, the feedstock is also currently available on the Island of Maui. HC&S has an excess of bagasse that could be used in an ethanol-producing plant using lignocellulose feedstock. Maui also has over 239,000 acres of forested land, of which 67,500 is commercial acreage (State of Hawaii Data Book, 1979).

The Puna area can be considered the center of the papaya industry in the state. In 1979, the Big Island produced about 75 percent of the papayas marketed in the state, and most of the papaya-producing acreage on the Big Island is in the Puna district. The use of geothermal energy in the papaya industry is geographically feasible. The geothermal park being studied by Hawaiian Dredging and Construction has incorporated plans for a papaya processing plant. Currently, the bulk of the papaya marketed -- about 89 percent -- is sold fresh, and the rest is processed as puree. The proposed park investigates the possibilities of processing fresh fruits, pureed products, and a dehydrated product. The dehydrated product would be a new use for the papaya.

The fresh fruit does bring in the best price to the farmer and processing the fruit provides a way to utilize fruit that would otherwise be left as waste in the fields. The Papaya Administrative Committee estimates that in 1978, a peak year in papaya production, about 18 percent of the crop was left in the fields. Processing of more fruit should not adversely affect the current fresh fruit market if more of the discarded culls are used. It is believed that the market for all papaya products is capable of expanding. The market for puree is expanding on the mainland and into other parts of the world. The market for dehydrated papaya should also find acceptance, especially in a market looking for a healthful snack.

Currently, only fresh fruits and purees are being mass marketed. A firm in the Puna area, Malo'o, is drying papayas using a solar process. Although this is being done on a very limited basis their marketing efforts have reached the mainland and foreign countries. The product is not unlike dried apricot in texture and flavor. The process being considered for use in the geothermal park setting is a new deBevic process that would produce a different type of product that would taste more like the fresh fruit. The deBevic process being considered would require heat in the range of 140°F to 150°F.

The market for purees holds possibilities for export expansion. The marketing efforts of the industry will determine the success of the market expansion (Ishida, 1978). According to the assessment by the state, the local market for tropical fruit purees has been saturated, so expansion of the market will necessitate exportation. Currently, papaya purees are manufactured on a small scale. The current practice requires chilling of the juice throughout the distribution system. This method would be able to utilize geothermal energy in the area of absorption cooling.

An alternate puree-processing method is also being considered for the geothermal park project. The "aseptic" method, now being tested by Puna Papaya, would heat the juice to 205°F then quickly cool it to 80°F. The advantage of this process is that the product does not require refrigeration. This would extend the shelf life of the product and reduce distribution problems. The processing of fresh fruits also has heat requirements.

Fresh fruits are immersed in water at about 120°F to kill any larvae that may be on the skin of the fruit. The fruits are then sprayed with cold water to prevent overheating. Geothermal energy could be used both to heat the water and to provide a cooling system for the cold water requirements.

Fruit processing in the Puna area need not be limited to papayas. The Puna area is also the hub of the guava industry, and most of the banana producing lands on the Big Island are in or close to the area. Since transportation costs are high the processing of fruit close to the production site holds merit. The Big Island produces about 30 percent of the bananas in the state. All of the bananas are sold fresh. Processing is almost nonexistent. Currently, some farmers on the Big Island are considering processing bananas into purees and/or dried fruits. The papaya processing experience would be applicable to the processing of bananas.

All of the guavas sold commercially, on the other hand, are processed. In 1979 about 6.5 million pounds of guava were processed. They are pureed to be made up later into different final products. About one-half of the guavas produced in the state come from the Big Island. Utilizing geothermal energy in the guava processing operations offers possibilities for a deeper vertical integration. The guava purees could be processed into final products such as jams, jellies, etc., utilizing geothermal heat. Processing of these agricultural products is not incompatible with the activities of the Puna area, and utilizing the geothermal energy in the processes could provide a boost to the economy of the area without much disruption of current commercial activities.

B. Ka'u District, Big Island

Sugar is the base of the economy in Ka'u, although diversification is beginning. Ka'u Sugar Company's factory is close to the potential resource along Kilauea's southwest rift. If the resource is of an adequate temperature and pressure, sugar processing in Ka'u could be a market for the geothermal energy. Ka'u Sugar uses about  $1.572 \times 10^{12}$  BTU's of process heat energy per year (Science Applications, Inc., 1978).

The processing of macadamia nuts may provide a possible market for the use of geothermal energy. Macadamia nut trees have been planted in the Ka'u area by the C. Brewer Company and the plantings are expected to increase. Over 99 percent of the macadamia nuts in the state are grown on the Big Island. If macadamia-nut processing were done in Ka'u, the operations could also possibly process the crop from "The World's Largest Macadamia Nut Orchard," which is located within 30 miles of the resource at Ka'u.

C. North Kona District, Big Island

North Kona has two distinct industries. Agriculture is predominant along the slopes, and tourism reigns on the coast. Coffee remains the major agricultural crop in the North Kona area although diversification into other crops has begun and coffee production has been decreasing. Processing of the coffee is done primarily in South Kona. The Kona Farmers Cooperative processes both coffee and macadamia nuts in their plant in South Kona. About 1.4 million pounds, in shell weight, of macadamia nuts and an equal amount of coffee, parchment weight, were processed in 1979. Direct-heating requirements for both were not great. In 1979 the operation used about 1,300 barrels of oil to fuel the 100-horsepower boiler that provides 140°F heat to dry both the coffee and the nuts.

Coffee production is not expected to increase, but macadamia nut production may, if trends in other areas are followed. The macadamia nut industry is quite competitive and bidding for the raw nuts is active. Farm prices have increased from an average of 31.6 cents per pound in 1975 to advertised prices of over \$1.00 a pound in recent months. If the trend continues, the Cooperative or another company may see an advantage to using geothermal energy to process the nuts. The purported "World's Largest Macadamia Nut Orchard" is also about 30 miles from North Kona. And a nut-processing plant could also possibly pull in those harvests.

The Kailua area has long been recognized as a visitor playground. The royal families of Hawaii used Kailua as their summer home, and today sport fishing continues to draw visitors to the area. A spa may not be out of place in this environment. In the town of Kailua itself, the resource could be used for space cooling and water heating. The town has a tight cluster of restaurants, small retail

units, hotel units, business offices, medical offices, shopping centers, and an area for light industry. Although there are no aquaculture activities in the North Kona area, there are extensive secondary aquaculture development lands identified by the state. If the geothermal fluids could be used as the culture medium, it would prove to be a boon to aquaculture development because the identified areas are generally dry.

D. Kawaihae Area, Big Island

The Kawaihae area, between the harbour and Anaehoomalu Bay, is experiencing rapid development as a tourist destination. The famous Mauna Kea Beach Hotel will be joined by two other developments further down the coast towards Kona. Mauna Lani Resorts plans a complex close to Puako, and Sheraton is constructing a hotel complex at Anaehoomalu Bay. The Mauna Lani complex, when completed, it will have 3,000 hotel units and an equal amount of condominium units. This is a possible market for space cooling or hot water requirements. A geothermal resource utilized in a spa type of facility would not be out of place in this area. The exclusive atmosphere of the Mauna Kea Beach Hotel has served to compensate for the lack of activities offered by the area in general. If a spa in this area can create the same aura, it may be able to establish itself in the same way that the Mauna Kea Beach Hotel has.

The proximity of the harbour to the potential resource may hold the possibility of drawing industrial users to the area. One possible use for geothermal energy would be to provide absorption cooling for a refrigerated storage facility at the harbour. The demand for such a facility is not great at this time. In 1977 about 11,500 tons of produce were shipped from Kawaihae (County of Hawaii Data Book, 1977). About 25 percent of all the goods shipped out of Kawaihae are fresh produce. Currently, the produce growers harvest their crops the day before the shipments from Kawaihae are made. The produce is taken to the docks, loaded onto refrigerated containers, and shipped out the same day. A refrigerated storage area may provide more flexibility to the farmers of the area. Further investigations would have to be made of the benefits of a refrigerated storage area. The availability of such a storage area may affect the entire interisland shipping procedure. Such possibilities would only be discovered from an intensive study of the situation. Aquaculture activities are found in the South Kohala area, about 25 miles from Kawaihae Harbour. The operations are currently limited to the production of prawns, but other types of aquaculture are being considered. Kona Aquatics has the only commercial operation at the present time, but others have indicated an interest in venturing into this field.

E. La Perouse Bay, Maui

The tourist destination area stretching from Kihei to Wailea is near the potential geothermal resource in the La Perouse Bay area along Haleakala's southwest rift. The Kihei area has experienced a 300% increase in population in the past decade, fueled primarily by an increase in visitor-related industries. A spa would fit in with the present activities of the area. The tourist-related activities could also use the geothermal potential for space cooling and water heating. A recent count showed over 3,000 hotel units in the Kihei/Wailea area.

An aquaculture venture raising catfish is currently being considered for the Kihei area. Catfish have been raised successfully in geothermal fluids on the mainland. The planned aquaculture project will be located next to the Maui Electric power plant, but the project will not be able to use the effluent from the plant because of the salinity of the fluid. This venture may provide the impetus for other similar attempts, thereby providing a market for a low-temperature geothermal resource. As in the North Kona area, the geothermal resource could be used to provide a stable, optimal growth temperature.

A possible problem that may be encountered is the current designation of the area around the bay as a conservation zone. Whether geothermal development will be allowed is unknown.

F. Haiku/Paia Area, Maui

A high-temperature resource in the Haiku/Paia area could be used in the HC&S factory in Paia. In 1975 the process-heat requirements for the factory were  $1.979 \times 10^{12}$  BTU's (Science Applications, Inc., 1978).

HC&S, the largest sugar processor in the state, has two factories on Maui. The factory at Paia is the smaller. HC&S currently sells to the utility electricity generated from the burning of bagasse. If geothermal energy were to be used in the Paia factory, the steam that is now used to process sugar could be diverted to generate more electricity.

The Haiku/Paia region, which is close to the commercial center of the island, Kahului, could facilitate the relocation or startup of businesses in this area. Kahului Harbour is the only deep-water port on the island. The town of Haiku is

about 8 miles from the Kahului airport. Proximity to the major transportation lines could be an important factor in attracting direct-heat users to the area. No aquaculture developments are underway in the area but the state has identified primary and secondary aquaculture lands that, if developed, could use the lower-temperature geothermal resource.

G. Olowalu/Ukumehame-Lahaina/Kaanapali Areas, Maui

The potential resources in these areas tend to overlap one another. The areas are within ten miles of one another and the applications would be to some of the same potential markets. The one energy-intensive user would be Pioneer Mill in Lahaina, a sugar milling operation. In 1975 the process heat requirements at Pioneer Mill were  $1.5 \times 10^{12}$  BTU's, (Science Applications, Inc., 1978), and the mill has been active in its efforts to relieve its dependence upon oil. A study is being conducted on the feasibility of a solar tower to provide energy for factory operations. Pioneer Mill is also considering the possibilities of providing electricity to the utility.

The Lahaina/Kaanapali area is Maui's favored tourist destination. Over half (62 percent) of the hotel-room inventory on the island is in the Lahaina/Kaanapali area, and a spa would probably fit into the current usage of the area. Many of the amenities and infrastructure to facilitate development of a spa now exist. Geothermal energy could also be utilized to provide the heating and/or space cooling for the various hotels and businesses in the area. The Kaanapali resort area is an example of a possible market. Bordered by the Sheraton Maui Hotel and the Hyatt Regency Maui, the resort area has hotels, condominiums, restaurants, retail stores, and business offices that could use the heating or cooling provided by the resource. Lahaina and Olowalu have been identified as having primary aquaculture lands, but no ventures into this industry have begun in these areas.

H. Lualualei Valley, Oahu

Lualualei is the only potential on Oahu that has been explored in any depth. The expected temperatures of under  $150^{\circ}\text{C}$  would require low-temperature applications. West Beach and Makaha have been designated as tourist destinations by the state but neither has the intensive development of other places on Oahu or the other islands. Whether this would work to the benefit or detriment of a spa in the area would depend on the development of the spa itself. A spa would be able to fit into the current designations of the areas.

A low-temperature application for the energy would be to heat the brooders in the poultry industry, although the heating requirements are not very great. (A large scale egg producer in the area claims no heating requirements.) Currently, one of the largest producers uses about 5,000 gallons of liquid propane each year to meet heating requirements.

Poultry farmers have expressed concern about the disposal of the manure. The supply of the product is outstripping the demand. Potential buyers are reluctant to use the product for aesthetic reasons, but drying the product may help overcome this problem. Currently, only air drying is done, and this only on a limited basis. Energy costs preclude any other means of drying the product. The use of geothermal heat here may provide another new market for the heat in the same industry. Further investigations may be warranted. Lualualei also has been identified as having primary aquaculture lands.



## VI. WELL-DRILLING TECHNOLOGY

### A. Introduction

Drilling geothermal wells probably represents the greatest expense and the greatest risk in geothermal-energy utilization. Once a geothermal-reservoir prospect is fairly certain, the next step is to confirm the size and usefulness of that resource, and confirm the economics of getting the energy out of the ground and using it for a period of time sufficient to amortize the investment that will need to be made. The only positive method of confirming the potential reservoir is through drilling test wells or production wells. In addition, the techniques, considerations, and plans for reservoir development and management differ for direct use versus electrical power generation applications. In the following paragraphs the various types of drilling equipment, well design considerations, well casing methods, well drilling problems and safety considerations, drilling costs and drilling regulations are described.

### B. Drilling Equipment

Geothermal wells are commonly drilled by rotary drills. A typical rotary drill rig is shown in Figure 9. The bit resembles a drill, even though its drilling action may be as much chipping and crushing as it is cutting. The cuttings are removed from the hole by fluid circulated down the drill pipe and up the annulus between the drill pipe and casing. (Reverse circulation is rarely considered appropriate.) Several types of fluids can be employed:

#### 1. Water or Mud

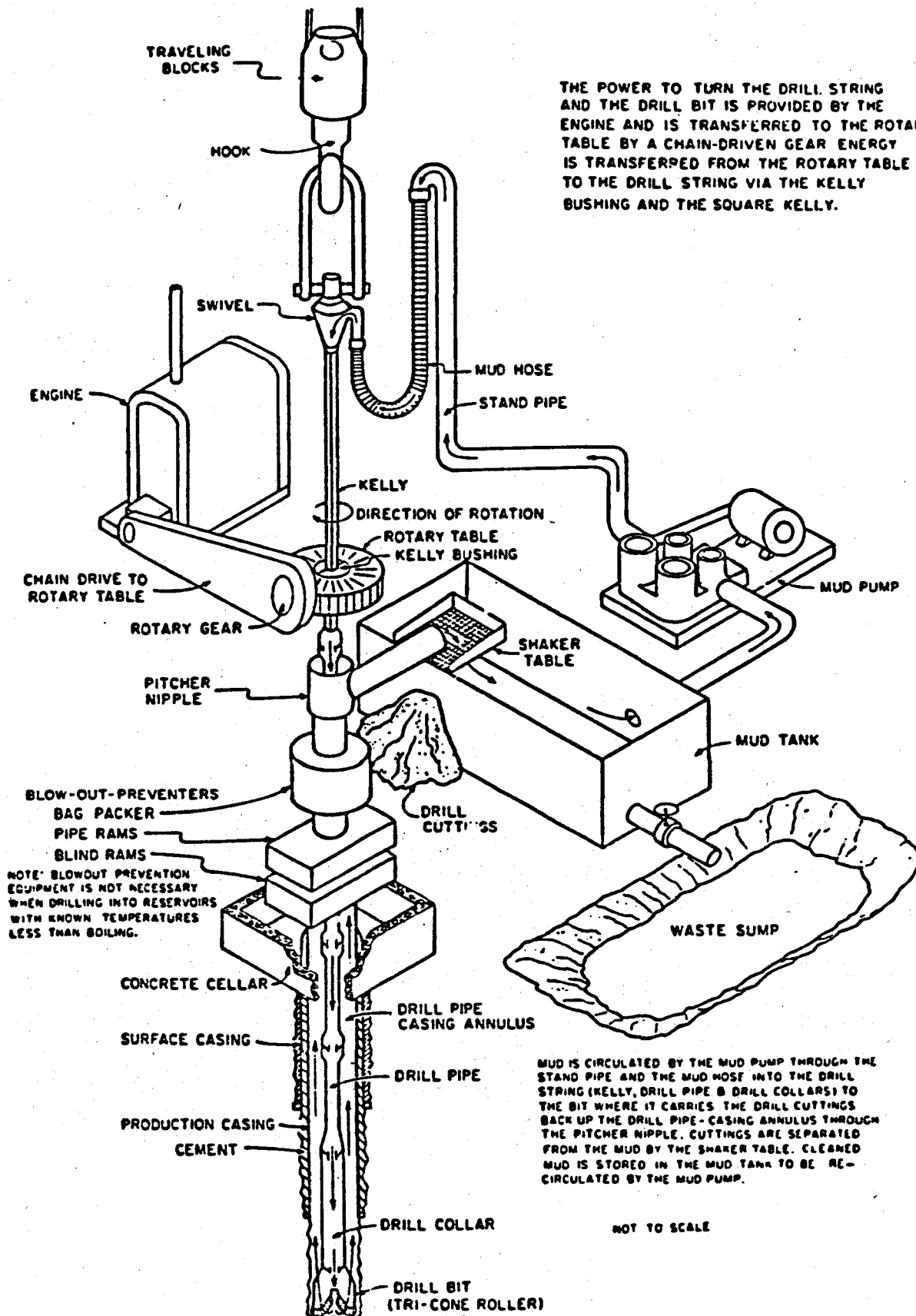
The use of mud is preferred where caving of the sidewalls is a problem but should be avoided in geothermal production zones. The heavier density of mud helps to contain high pressures in gas wells so operators of large rotary drilling rigs are accustomed to using it.

#### 2. Air Mixed with Water and a Foaming Agent

This technique further lightens the column of drilling fluid, making it easier for the geothermal water to enter the well bore.

FIGURE 9

BASIC ELEMENTS OF A ROTARY DRILLING RIG



### 3. Air Alone

Air is used where water or mud is being lost in the formation. If adequate makeup water is available, continuing to drill with water is advisable because it is superior to air in its lubricating and cooling qualities. Air is commonly used for water-well drilling, because air techniques enhance the ability to detect the water-bearing zones. Air drilling does require large compressors and high pressures. Work around high-pressure pneumatic systems is hazardous and, consequently, expensive. Air streams carrying the cuttings past the drill pipe create a very erosive environment for the pipe. Frequent replacement of drilling pipe is needed in air drilling operations.

Typically, 200- to 400-horsepower engines are needed, one for rotating the drill and one or two for lifting the pipe out of the hole. A mud pump and a spare (about 200-horsepower each) are also needed. Thus fuel to operate these rigs can cost \$500 to \$1,000 and more per day.

#### C. Well Design Considerations

Casing size, particularly at the bottom of the casing string, and the diameter of the hole in the producing section need to be established before the size of the well at the surface can be determined. In general, the production of the well will depend partially on each of the following:

1. Surface area of well bore in the producing zone (i.e., nominally proportional to diameter of well).
2. Pressure drop from bottom of well to the top (i.e., inversely proportional to the diameter to the 3.75 power).

Thus, for deep wells (greater than 2,000 feet) (2) is a major consideration. For shallower wells, (1) is the major consideration. However, in the case of poor permeability ("tight" wells) or predominate fracture permeability, the production capability is quite insensitive to the diameter of the well bore.

#### D. Casing Types

##### 1. Anchor Casing at the Top of the Well (Conductor Pipe)

This casing may be 20 to 80 feet long cemented into the ground to thoroughly anchor the well against high pressure inside and the punishment of the drilling operation. This casing is usually installed in a concrete-walled cellar (for the bigger and deeper wells) to allow room for the drilling equipment, valves, etc., between the conductor pipe and the drilling-rig platform.

##### 2. Surface Casing

The next string of casing is usually required by regulation to protect the drinking-water aquifer from contamination by geothermal water. This surface casing might eventually contain the pump turbine. The surface casing is cemented to the surface with a 2- to 4-inch annulus between it and the conductor pipe. The surface casing usually extends deeper than that of nearby domestic water wells, and the main valve and various pieces of safety valve equipment are attached to its head.

##### 3. Production Casing

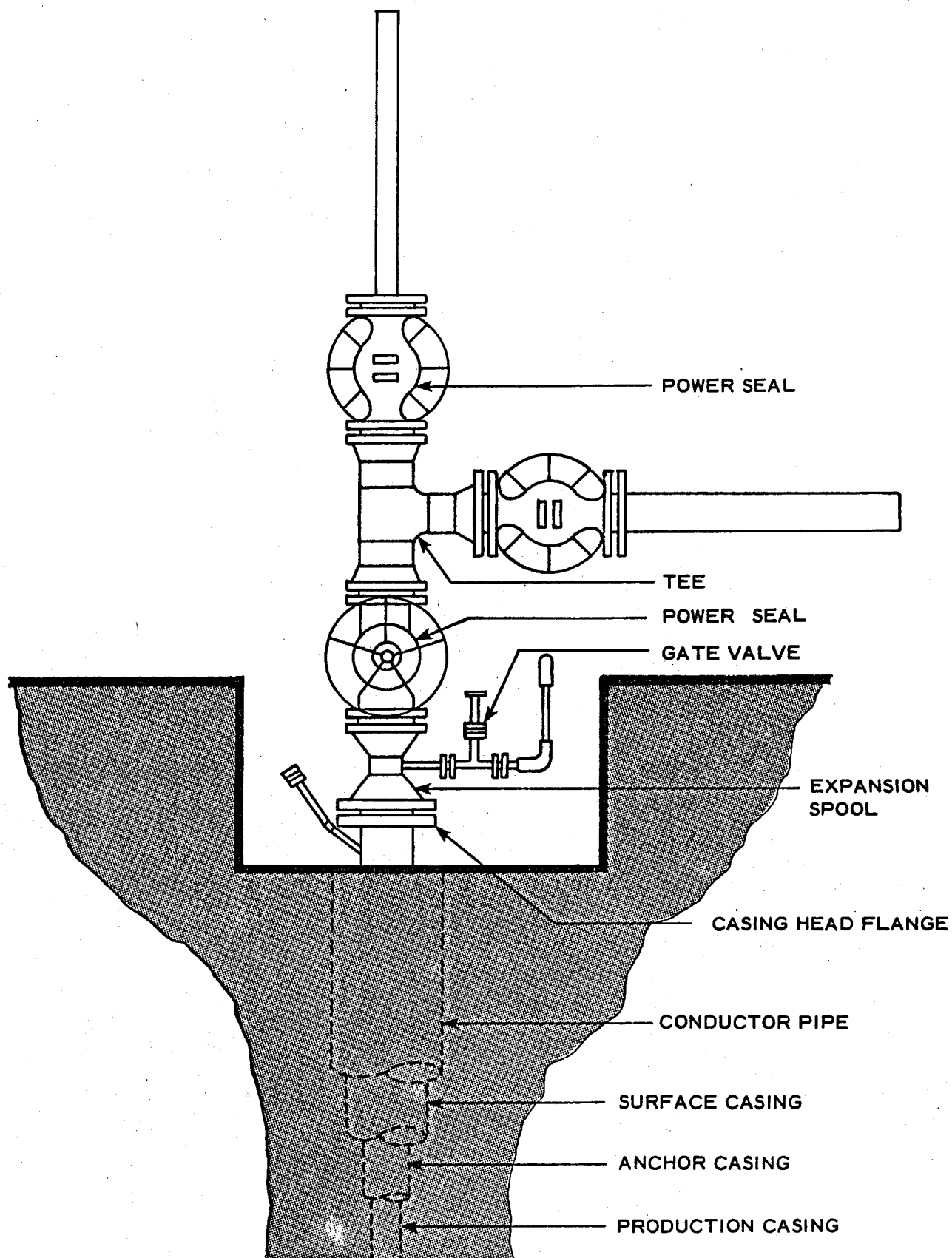
The production casing protects the sidewalls of the well against collapse and conducts the fluid to the surface. It must also contain the down-hole pump, unless regulations allow the surface casing to be used for this purpose on the lower-temperature wells. In that case, a "casing hanger" is used to hang the production casing near the bottom of the surface casing.

Figure 10 shows typical well construction.

#### E. Geothermal Well-Drilling Problems

Geothermal drilling has two concerns that essentially demand contradictory approaches to drilling technique. These must be assessed for any particular geothermal well-drilling situation, and the most critical concern at that point in the drilling operation is to allow one to take precedent over the other. The two concerns are as follows:

FIGURE 10  
TYPICAL WELL CONSTRUCTION



1. Caving In of the Hole

This is the bane of drillers and rig operators and is most likely to occur in the loosely consolidated formations in the first few thousand feet. Generally, at greater depths, years of high pressure and moderate temperature have cemented or consolidated the sediments. The common methods to avoid this problem are the use heavy drilling fluids (called mud) having 1-1/4 to 1-1/2 times the density of water and approaching the density of the formation.

2. Avoiding the Use of Heavy or Unnatural Fluids in the Suspected Production Zone

Using heavy drilling fluids makes it difficult to identify the geothermal-producing strata. This requirement, of course, clashes with (1) above. The reasons for avoiding heavy drilling fluids are as follows:

- a. Heat in the geothermal zone may help solidify the drilling mud in the fractures, and the mud may actually develop the qualities of a cement.
- b. Chemical reactions, especially at the higher temperatures, may contribute to the mud sealing the pores in the rock formation.
- c. The weight of the mud can prevent the geothermal water from entering the hole, thus the driller has no clue that he has encountered the resource.

The latter concerns are extremely important in geothermal drilling, because they block all indications of the proximity of the geothermal source. Hence, in the production zones (suspected or otherwise) the driller may just have to take his chances, drilling with water or with water made lighter with air, hoping that the sidewalls will not cave in on him and that geothermal water will leak into the well bore. Keeping the fluid circulating and getting the drill string out of the hole as quickly as possible (when circulation is stopped to remove the bit) are extremely important.

## F. Geothermal Well-Drilling Safety Considerations

The following safety factors should be considered during the determination of the well-drilling operations and methods. Much of the information given below is discussed in greater detail in GRC (1979).

### 1. Temperature

A temperature hot enough to scald (above 140°F) requires having face shields, wet suits, and insulated gloves available. Temperatures above boiling should be treated with the respect given to any steam system, with applicable codes, personnel protection, and operating procedures to prevent accidents.

### 2. Free-Flowing (Artesian) Wells

Two conditions can create water flowing free at the surface. The first occurs when the geothermal reservoir is fed from a higher elevation and covered by a layer of cap-rock. If the well bore is not sealed and is not filled with heavy mud no amount of cold water will kill the well once it starts flowing. These wells present special drilling problems during casing and cementing. It is thus desirable to complete these operations before drilling through the cap-rock and into the resource production zone. If this is not possible, the use of heavy muds may be considered. Alternative methods are to back-fill with sand (and to drill the sand out later) or to kill the well with salt water with density up to 1.2 times the density of ordinary water (if a suitable means of avoiding environmental contamination is available).

The second condition leading to artesian wellhead pressure is a density difference between a hot-water column in the well and a cold-water hydrostatic head above the geothermal reservoir. The following table lists the pressure differences between hot water at various temperatures and 68°F cold water, per 1,000 feet of vertical height.

102°F	2.8 psi
153°F	8.7 psi
193°F	14.5 psi
212°F	17.8 psi
240°F	22.7 psi
281°F	31.0 psi
302°F	35.8 psi

Since 1.0 psi will elevate water 2.3 to 2.5 feet, depending on the temperature, the hot leg can stand substantially higher than the normal water table, perhaps enough to make the well free flowing at the surface. This type of well can be killed by pumping cold water into it. It can be restarted by air-lifting or by swabbing (pulling out a loosely fitting piston at a rapid rate).

### 3. Casing Thermal Expansion

The expansion differential between the casing and the material that it contacts (the cement, for instance) is a significant problem, as is the thermal expansion of the casing itself if it is allowed to expand freely.

These effects are insignificant in ordinary water wells and usually of little concern in oil wells. But in geothermal wells, casing expansion, even during the casing installation operations, must be carefully considered to insure the inclusion of the appropriate allowances and clearances.

The most common practice today is to cement the entire surface and production casing thoroughly in place with a tight bonding cement. Afterwards, casing expansion can be ignored, unless the bond breaks. To minimize this possibility, operation of the well throughout its lifetime should be so planned as to limit the number of "ratcheting" thermal cycles -- i.e., keeping the well hot even when it is not being used.

### 4. Containment of Drilling Fluids and Well Production

State of Hawaii geothermal well-drilling and environmental regulations will not allow disposal of either drilling fluids or the produced geothermal fluids on the surface until it is proven that these do not affect the local environment. Therefore, all drilling operations must consider using hold-up ponds (reserve pits) and the necessary mechanisms to direct the fluids into these pits. Also, a reserve supply of cold water must be available for makeup water, if needed, and for cooling the well should an emergency arise.



## VII. HYDROTHERMAL FLUID TRANSPORT

### A. Introduction

This report identifies and discusses various factors affecting the transport and transmission of hydrothermal fluids; the use of hydrothermal resources for direct use and electrical energy generation purposes; and the transmission of electrical energy generated via hydrothermal resources. Unless noted otherwise, the terms "hydrothermal" and "geothermal" resources, as used in this report, are to be considered synonymous.

The general arrangement of the report is from an overview of the subject to a more detailed analysis of how, when, and where the subject is applicable to the Hawaiian geothermal resource environment. Specific attention has been given to identify a topic's relevance to particular Hawaiian Island areas that are known or identified as potential utilizable geothermal resource areas.

The engineering literature is resplendent in detailed technical engineering terms, formulas, and particulars regarding specific geothermal resource utilization projects. Although there are some common elements, the majority of the projects discussed are unique. This factor indicates that generalizations should be used with caution when discussing the various aspects of geothermal resource utilization.

### B. Background Review

Geothermal fluid transmission pipelines represent one of the largest capital investment items in a geothermal system. Ideally, the well field and the geothermal fluid user should be located as close together as possible. It is important that the transmission lines be properly designed, installed, and insulated to reduce both heat loss and maintenance costs. Transmission lines at developed and operating geothermal fields are generally less than 2 miles long. This includes the developed fields in the mainland United States, the USSR, the Philippines, Iceland, Japan and Italy.

In contrast, the majority of studies conducted to date in Hawaii have attempted to economically justify the use of much longer transmission lines. This has been due, in part, to the fact that the most promising geothermal reservoir sites are usually far removed from established commercial, industrial or agricultural areas. For example, Puna Sugar Company undertook a study (Humme, et al., 1979) to utilize geothermal fluids in an established sugar mill approximately 16 miles from the proposed well field. The costs associated with this plan indicated, at best, a marginally economical venture. Similarly, a yet uncompleted study of developing a geothermal industrial park in Pahoa, Hawaii, appears to indicate similar conditions that are, in part, due to an approximately 8-mile-long transmission line /Hawaiian Dredging and Construction Company, (HD&C), 1980/.

From the above and a review of the literature, it would appear that the maximum length of a transmission line probably lies somewhere between 2 and 4 miles, depending on the quality (pressure and quantity) of the hydrothermal fluid.

#### C. Physical Characteristics of Hydrothermal Fluid Transmission Lines

##### 1. Flow

For steam to flow in a piping system, there must be a difference in pressure, a higher pressure on the inlet side than on the outlet side. Steam flow in a pipe is "held" back because of the friction between the steam and the pipe wall; this is called the "line friction loss." The faster the flow or the greater the quantity flowing per unit length of line, the greater the "line friction losses." For a given difference in pressure at the inlet and outlet, the rate of flow accordingly decreases as the length of pipe increases (increasing line pressure losses) or the rate of flow increases as the pipe diameter increases (less line pressure losses). These losses, for various quantities and velocities, can be calculated using developed formulas and/or charts (Shaw and Loomis, 1965).

For any pipeline system, the conditions at the inlet and outlet must be established from known or assumed data. The quantity to be transported and the affordable loss in pressure will determine the size of the pipe. To determine the optimum size of the pipeline, one must determine the least pipe size to transport the geothermal fluid at the allowable pressure drop. For example, if the inlet condition is 110 psi and the outlet or plant-use requirements are 100 psi, then the total line losses allowable are 10 psi for the full line length.

## 2. Condensate

Geothermal steam is generally wet-saturated (i.e., water is in a vapor form with free moisture particles in suspension). Condensation will occur with a drop in temperature and/or pressure. Therefore, as the steam travels throughout the pipeline, condensate (water) is formed and must be periodically drained. If the volume of the condensate build-up in the pipeline is too great it will restrict the flow of steam. Pipelines are generally installed on a slope in the direction of flow. Low ends are provided with condensate traps and automatic drainers which are either float or thermally operated. Disposal of condensate may be handled in various ways:

- o Into a pipeline and disposed of at a remote well or evaporation pond.
- o Directly to surroundings, ditches, or drainage channels.

Regardless of the type or means of disposal, the condensate must be disposed of in an environmentally acceptable manner.

## 3. Types of Pipes

The information presented below is taken in part from GRC (1979) and Parsons' previous experience with geothermal piping systems.

a. Metallic Pipe

The most commonly used pipe is black steel, schedule 40, for pressures under 125 psi. The joints of this pipe may be threaded, welded, or use gland-type fittings. It is necessary to research the chemical and temperature range of the elastomeric gaskets to be sure they are compatible with the fluid chemistry.

When buried in the ground, metallic piping is normally jacketed and coated for corrosion-protection purposes. The use of sacrificial anodes or impressed electrical current to offset the electrochemical corrosion of soils and ground water is generally advisable, particularly in very moist soil or highly acid or alkaline soils.

b. Nonmetallic Pipe

Polymer concrete pipes (mixtures of cement aggregate and various polymers) are presently under development. These pipes have been tested in various geothermal fluids and have been found to be resistant to leaching, scaling, and erosion. The pipes are commercially available, but at present there is no large commercial application experience.

There are many types of patented plastic pipes, such as PVC, CPVC, fiberglass, polypropylene, and other thermoplastic materials that have excellent chemical resistance and sealing, high flow rates, and a wide range of thermal expansion and temperature characteristics. These materials have been used in only limited applications to this time, and there is little experience on which to base design or operation and maintenance costs.

Some fiberglass-reinforced plastic (FRP) pipes meet rigid military specifications of up to 115 psi at 300°F and have been used with good results for steam-condensate lines. Maintenance costs to date have been nil and the piping shows no signs of deterioration. FRP in general will not carry live steam as the steam breaks down the plastic.

#### 4. Expansion Allowances

Consideration must be given to the expansion and contraction of piping due to temperature changes. Expansion must be taken up within the piping system either with offsets or pipe loops, expansion joints, or special mechanical couplings, by utilizing the inherent flexibility of the piping in bending. Preheating or "cold-springing" are also used to preset the piping for given or known expansion allowances.

#### 5. Corrosion and Materials Selection

Properly managed boiler water, steam, or hot-water heating systems are free of the typical level of geothermal fluid components, i.e., dissolved solids and gases. These fluids are substantially less aggressive than geothermal fluids and have little tendency to form scales by deposition of dissolved solids. The chemical species present in geothermal fluids are the primary factors that result in corrosion and scaling when their fluids are used as heat sources.

However, as long as the fluid temperature is kept high by keeping the fluid under pressure, the chemical species remain in solution and do not cause corrosion or scaling to the piping or equipment systems. Certain important species are found to a greater or lesser extent in all geothermal fluids and are tabulated in Table 3; those found in Hawaii geothermal fluids are shown in Table 4.

The volumes of fluid required for most geothermal-heating applications are typically too large for the economical use of corrosion inhibitors. In addition, the Environmental Protection Agency (EPA) requires that any chemical added to the fluid for corrosion control be removed prior to disposal. These factors suggest that materials selection is the most economical means of corrosion control.

Based on the HGP-A fluid chemistry given in Table 4, it is likely that standard black steel schedule 40 piping will serve most Hawaiian geothermal projects adequately. However, the corrosion and scaling factors appear to require additional information before final pipeline materials can be selected. This information should soon become available now that the HGP-A well has begun operation. Other transmission line factors, such as expansion allowances and insulation materials, should also soon be standardized.

TABLE 3

**DISSOLVED MAJOR CORROSION AND SCALING SPECIES  
IN MOST GEOTHERMAL FLUIDS**

<u>Corrosion</u>	<u>Scaling</u>	<u>Character</u>
Oxygen (in leakage)		Gas
Hydrogen Sulfide		Gas
Carbon Dioxide		Gas
Ammonia		Gas
Hydrogen		Ions
Sulphates		Solid
Chlorides		Solid
	Silicates	Solid
	Carbonates	Solid
	Sulfides	Solid
	Oxides	Solid

Source: Geothermal Resources Council. 1979. Direct Utilization of Geothermal Energy: A Technical Handbook. Special Report 7.

TABLE 4

**HGP-A GEOCHEMICAL SUMMARY**

Chemical Constituents (mg/l of total discharge)

<u>LOCATION</u>	<u>Cl</u>	<u>Na</u>	<u>K</u>	<u>Ca</u>	<u>Mg</u>	<u>SiO<sub>2</sub></u>	<u>s<sup>=</sup></u>	<u>pH</u>	<u>TRIT.</u>
DOWNHOLE									
Nonflowing									
(ave. of 5									
profiles):									
mean	1040	730	122	91.2	1.0	440	135	3	0.1
	<u>+465</u>	<u>+272</u>	<u>+46</u>	<u>+63</u>	<u>+0.7</u>	<u>+230</u>	<u>+96</u>		
WEIR BOX									
Approximate									
steady-state	780	390	68	24	0.11	41	---	8.5	---
CARRY OVER									
(Based on									
Separator	2.1	1.5	0.2	0.2	0.0	0.9	0.3		
Efficiency									
of 99.8%)	<u>+0.9</u>	0.5	0.1	0.1	0.0	0.5	0.2		

Source: Humme, J.T., et al., 1979.

#### D. Transmission Line Routing, Safety, and Security Factors

The routing of hydrothermal transmission lines is generally a function of two interrelated factors: distance to user and terrain. As indicated previously, in order to have an economically viable geothermal project, the transmission line distances should be kept to within 2 to 4 miles. Therefore, it is at times necessary to excavate pipeline trenches to maintain a downhill slope to effect flow of condensate and to maintain the shortest distance between the wellhead and the using facility. The route the transmission line follows must also take into account the requirement for expansion joints or loops as well as the environmental factors that will be discussed below. In general, the transmission line routing is a mechanical/civil engineering design question, with each project having its unique problems and solutions.

The safety and security factors associated with transmission lines are those elements designed into the system routing to protect the general public from potential pipeline malfunctions and to protect the pipeline from the general public. For example, condensate traps and pressure relief valves can suddenly release large quantities of hot fluids. Therefore, in order to protect the general public from these hazards and to protect the pipeline from vandalism or other acts, the pipeline should either be buried in a covered trench or protected by fencing.

In Hawaii, it is presumed that standard engineering and safety precautions will be taken to protect both the general public and the transmission line. This will include security fencing as required, trenching only where necessary, and sufficient detection devices to alert operators of transmission line malfunctions.

#### E. Transmission Line Visual and Environmental Factors

The majority of geothermal projects to date have not placed pipeline visual and environmental factors in top-priority positions. This is understandable for most projects, since they are generally located outside of the general public's view. However, both environmental and visual effects can be easily accommodated in the siting and routing of geothermal facilities. Pipelines are normally clad in metal coverings that could be painted to blend into the background, and wellhead systems can usually be curtained off from public view by landscaping. These items would add little to the overall costs of facilities and would give the generally stark industrial-type facilities a pleasant appearance.

Due to the acute environmental awareness prevalent in Hawaii, it is likely that the above noted transmission line treatments will be required for any Hawaii project. Painting pipeline claddings, landscaping, and other features would add to the acceptability of a given project by the general public.



### VIII. ELECTRICAL TRANSMISSION (OVERLAND)

At present, in Hawaii, most major power transmission lines are overhead lines. Also, each island has its own generating plant(s) and distribution system. In a few cases there are underground distribution lines, but these are limited to housing developments, downtown business districts, or industrial park areas and do not involve high-voltage (above 60 KV) transmission.

Present utility plans call for the improvement of the Maui, Hawaii and Oahu major transmission systems to accommodate growth patterns on each island. At present, it is not known whether the required extensions will be overhead or underground installations, but they probably will be in existing utility company rights-of-way or along existing public roadway rights-of-way. In addition, as part of their state-issued electric utility franchise, the utility companies have the power of eminent domain to establish rights-of-way on private lands. This latter power is only used as a last resort in those cases where negotiations with property owners cannot be concluded and suitable agreements reached by the property owner and the utility. Based on the foregoing, it is likely that new transmission lines will follow existing rights-of-way when and where possible. This policy will result in minimum environmental impacts and little change in established utility-line routings.

It is estimated that the AC transmission line costs will be approximately \$300,000 per mile, with an additional cost of \$500,000 for each substation. For DC transmission, assuming that the voltage transmitted is 250,000 volts, rather than the 138,000 volts for AC transmission, the line costs have been estimated by Parsons to be approximately \$240,000 per mile. However, other researchers (Hauth and Breuer, 1980) have indicated that DC transmission lines may be 70 percent less costly than AC lines. To these costs, however, must be added the costs of AC/DC conversion-inversion equipment. This equipment has been variously estimated to cost between \$13 and \$62.5 million in 1980 dollars. Also, electrical engineering handbooks (Fink and Beaty, 1978) show the costs of conversion equipment to be approximately \$250 per kilowatt. Hauth and Breuer (1980) indicate that DC terminal costs per K vary inversely with the system M rating. For example, a system utilizing 250 M will have terminal costs per K of approximately \$65.00. A 500 M system would have terminal costs of approximately \$45.00 per terminal K. The wide variation in equipment cost estimates is due to the site specific nature of DC transmission line projects and the present rapid advancements being made in DC conversion equipment technology. Obviously as DC transmission becomes more prevalent, the costs of conversion equipment are expected to decline.

## IX. ELECTRICAL TRANSMISSION (SUBMARINE)

A submarine transmission cable between the major islands is the keystone to the establishment of an inter-island electrical grid system. Without such a system, it is unlikely that the full potential of geothermal resources, for direct or indirect use, will become a reality. The primary market area for electrical power is Oahu, while the only known and proven geothermal resource reservoir is on Hawaii.

The most efficient way of transmitting electric power over long distances is by cable, sending it in direct current form and then converting it to alternating current before distribution to consumers. Power losses in transit amount to only about 5 percent via direct current but are significantly greater with alternating current.

To date the longest underwater power transmission cable is between Norway and Denmark, is only 78 miles long, and lies at a maximum depth of 1,800 feet. By contrast, a Big Island-Oahu cable would have to be more than twice as long and would lie at depths up to 7,000 feet. This means that the cable would have to be thicker and heavier than any ever built in order to withstand tremendous pressures, and this creates immense problems of deployment. The length of the cable is so great, also, that it would have to be spliced in many places - and these splices, ordinarily the weakest point in a cable system, would have to be as strong as the cable itself.

All of these technical problems require an immense amount of research and testing not only in order to develop a satisfactory cable but to develop a ship capable of laying and repairing it. The total cost of this feasibility study is estimated at \$17 million.

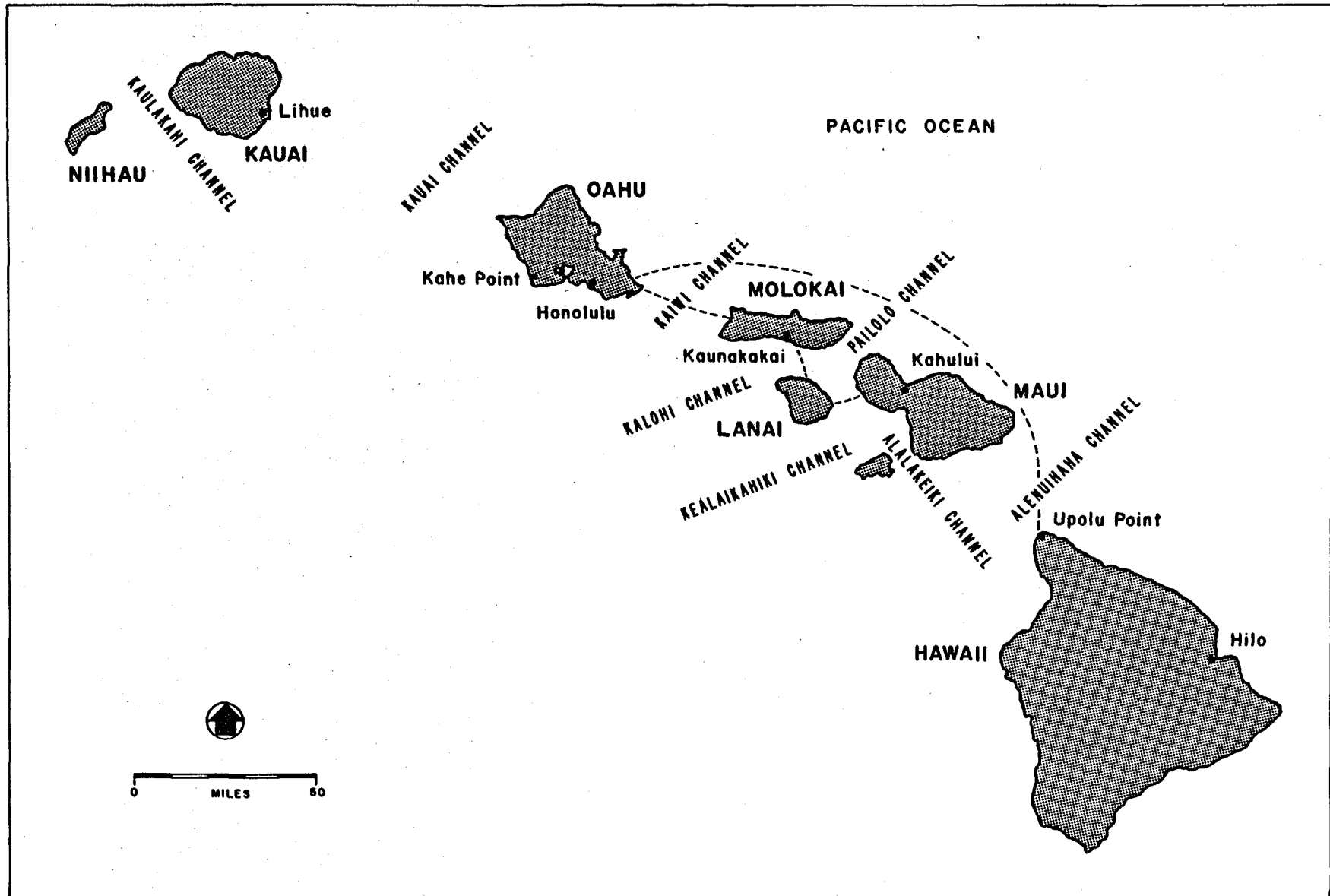
For the deep water cable project the State chose Hawaiian Electric Company as the prime contractor, and the utility picked Parsons Hawaii as the systems integration manager. Parsons is coordinating the technical work with the subcontractors.

This demonstration program is scheduled to be completed by the end of 1984, which may be optimistic as funding for the expensive later phases is uncertain. Even if this program is completed on schedule, it will take another three to five years to manufacture and install the cable, so at the earliest it would be the late 1980's before Oahu could switch on electric power from the Big Island. Figure 11 shows one proposed route for the deep water cable.

At this stage of the proceedings, any estimate of the cost of building and installing a 500-megawatt cable to run from the Big Island to Oahu is going to have a wide margin of error, but estimates now are in the \$400 million range. Development of the geothermal fields to supply the 500 megawatts of capacity will cost more than \$1 billion. But a 500-megawatt transmission cable would displace 6.5 million barrels of oil annually which in 1981 dollars would be worth \$250 million. A deep water power transmission cable has the potential for sustained long-term economic benefits for Hawaii.

FIGURE 11

PROPOSED SUBMARINE POWER TRANSMISSION CABLES, HAWAIIAN ISLANDS



## **X. COMMUNITY ASPECTS OF GEOTHERMAL DEVELOPMENT**

### **A. Introduction**

The purpose of this section is to identify and discuss potential non-technical barriers relative to accelerating the economically and socially sound utilization of geothermal energy in the State of Hawaii.

The sites that have been identified by the Hawaii Institute of Geophysics as having the highest potential for commercial development are predominantly in or near rural communities on the islands of Maui and Hawaii. Indeed, the only Hawaiian experience with geothermal energy development is near the rural town of Pahoa in the Puna District of the Island of Hawaii. Using the Puna District as a case study, it is possible to examine several social consequences of geothermal energy development that: (a) are ongoing concerns in the Puna District; (b) are generalizable to other rural communities in Hawaii that may experience development; and (c) have or may evolve into future barriers to development and commercialization.

### **B. Rural Lifestyle**

Rural lifestyle means different things to different people. Regardless of its specific definition, changes in rural lifestyle materializes as a social concern with regard to the potential effects of geothermal resource development. In most cases, the choice to follow a rural lifestyle is a conscious one (Dillman, 1977). As such, people in rural communities are engaged in a way of life they are extremely reluctant to change. The belief exists that geothermal resource development will change and possibly endanger the lifestyle that members of potentially impacted communities have come to enjoy.

Information reaching the community that has generated concern for change in or loss of the rural lifestyle has been at best partial and often inaccurate. In this regard, little or no information exists which objectively links the type and size of a geothermal energy project to the changes which would accompany it. Each project scenario will have different impacts upon lifestyle. In the absence of concrete proposals, people's visions will assume the worst possible case. This may put proponents of reasonable development in a defensive posture.

The issue of potential changes in lifestyle has already become a barrier to geothermal development in the Puna District. Lacking any survey data, the magnitude of resistance is uncertain. It is clear, however, that some people in the area are opposed to any change whatsoever. The Puna District, like other potentially impacted communities, has been experiencing changes in its rural character irrespective of geothermal resource development. That change is likely to continue. It has been suggested by some County officials as well as some Puna District residents that those people who are most vocal in decrying any change in the area are the same people who first initiated present changes through their in-migration. These people may have left the developments of the mainland for the charm of rural Hawaii and are now afraid that development has followed them.

A larger, albeit quieter, group of Puna residents are cautiously in favor of change. Their request is that the type and magnitude of change be made explicit and that they have a direct and meaningful role in formulating the future direction change will take in the community. As one community resident said, "This geothermal thing could be real good for us... if it doesn't get out of hand."

#### C. Visual Impacts

Closely aligned with the issues of rural lifestyle is the question of the visual impacts of geothermal resource development. It is quite understandable that people are concerned about how their community will look given the potential development of geothermal resources.

The quality of the information that has thus far reached the community level concerning visual impacts is often partial or inaccurate. Resource development has been equated with development in general (specifically tourist and land development) which may be an inappropriate conclusion. As with the information concerning the potential change in lifestyle, there has been no connection between the scale and type of resource development and the resulting visual impact.

In the case of the Puna District, the connection is often made between the geothermal fields at the Geysers in California, the Wairakei Field in New Zealand, and the potential development in the Puna District. The generalizability of either the California or New Zealand experiences to the State of Hawaii is questionable because the technology which produced these fields is several decades old and, in some cases, antiquated. In addition, geologic, hydrologic, and topographic features in Hawaii differ significantly from those of the Geysers and Wairakei.

Numbers and locations of wells, types and locations of end use facilities, and placement of transmission facilities are variables in determining the visual impact of geothermal resource development. In the absence of project and site-specific proposals, it can be expected that the question of visual impact will develop into a barrier to commercialization to the resource in each of the potentially impacted communities. With accurate visual representations which adhere to an agreed upon development strategy, the imaginations of community residents may not assume a worse case posture.

D. Economic Activity

Economic activity has a direct and immediate effect upon all aspects of community life. The potential changes in economic activity which may be brought about by commercialization of geothermal resources is thus a major concern to State and County officials as well as community residents.

The multiplicity of rumors concerning various end use scenarios has created speculation concerning economic opportunities. At the level of current development (i.e., limited direct use and minimal electrical production), geothermal resource commercialization is more capital intensive than labor intensive. Except for construction work during the development phase, no large direct job market is likely to be created in the near future. However, due to the relatively small populations of potential geothermal communities, a large job market may not be required to positively impact the unemployed. Indeed, if training programs were to be established, many of the jobs which will be created could be filled by local residents as opposed to in-migrants. An assumption here is that the unemployment rates for potential geothermal communities accurately reflect the number of people who are unemployed and wish to work at other than self-employed and/or unreported occupations.

The potential of increased economic activity, regardless of level, will meet the same kinds of responses in terms of community sentiment as does changes in the rural lifestyle. Those elements of the community which resist any change, will be opposed to increased economic activity for this will lead to some changes in lifestyle. Those who welcome change as positive will see increases in the economic level of the community as a positive aspect of geothermal resource development and a chance to enhance their lives.

## E. Utility Rates

Speculation abounds concerning the effect that geothermal resource development may have on the consumer electricity rate structure. At the heart of the issue is the question of trade-offs. Since the local community will experience the bulk of any negative impacts, the argument goes, why should not the residents reap some of the benefits in the form of lowered utility rates? This especially is true on the Big Island where some of the highest utility rates in the State are to be found. It is difficult for a consumer to accept that his or her utility bills will not decrease if the source of the energy comes from beneath their feet instead of the Middle East.

Several recent State and Federal statutes impact the effect geothermal resource development may have on utility bills. These statutes are: U.S. Public Utility Regulatory Policies Act of 1978 (PURPA); Act 102, Hawaii Session Laws of 1977; and Act 132, Hawaii Session Laws of 1978.

These statutes, intended to give developers of energy from non-fossil fuel the strongest incentive to displace imported oil, make it possible for them to receive from the electric companies prices for their energy equal to what the utility would have had to pay for oil-fired power. If geothermal operators agree to receive a price lower than the "avoided cost" of the electric company, savings can be passed on to the consumers.

Be that as it may, even if utility bills do not decrease, they may well be lower relative to what they would have been. This would occur because once the infrastructure is in place, the cost of using geothermal energy will remain relatively fixed.



## **XI. LEGAL AND POLICY ISSUES ASSOCIATED WITH MINERAL AND LAND OWNERSHIP**

### **A. Introduction**

This section identifies and assesses potential barriers to the commercialization of geothermal resources which arise as a function of the uncertainty of resource ownership. The section also explores surface ownership patterns and rights.

### **B. History of Minerals Rights Uncertainty**

In 1846, a statute was adopted which established the authority of the Minister to patent and sell lands. It required a clause "reserving to the Hawaiian Government all mineral and metallic mines of every description." The requirement for such a clause was omitted from the Civil Code of 1859. In 1900, Hawaii became an incorporated territory under the Organic Act. The land granting form was changed at this time and the mineral reservation clause was dropped. Most grants and patents issued between 1859 and 1900 contained the reservation although no longer required by the Civil Code (Kamins, 1979a).

In 1955, the Territory began to sporadically include a mineral reservation clause in grants and patents. In 1963, after a brief interest in bauxite mining, Hawaii enacted a statute declaring that "all land patents, leases, grants or other conveyances of state land shall be subject to and contain a reservation to the state of all minerals. . ." (H.R.S. §182-2/b/).

In 1974, the legislature attempted to bring geothermal resources under state ownership. It reasoned that most instruments of conveyance contained mineral reservations and therefore, declaring geothermal resources to be a mineral would unambiguously establish the state as the resource owner (Act 241, Hawaii Session Laws, 1974). Between 1900 and 1963, however, thousands of grants were made with no mineral reservation clause (Kamins, 1979b).

C. Legal Questions Regarding Resource Ownership Uncertainty

The confusing history of mineral reservations in Hawaii has led to two legal geothermal resource questions. As previously noted, some deeds include mineral reservations to the government of Hawaii at the time of conveyance. Others do not. Therefore, in light of this apparent contradiction, is a mineral reservation to be implied in some or all titles issued without expressed mineral reservations? As Kamins (1979b) notes, there is no case law in Hawaii which may be considered to be dispositive of the question.

The second legal question involves the definition of geothermal resources as minerals. Although many deeds and titles issued before 1974 do contain mineral reservation clauses, it was not until that year that the legislature defined the resource as a mineral. The question thus becomes, are geothermal resources included in mineral reservation clauses in grants issued prior to the 1974 amendment? Again, Kamins (1979b) notes that there is no Hawaii case law nor rulings in other areas of the Ninth Circuit which could be considered dispositive.

D. Resource Ownership Uncertainty as a Barrier to Commercialization

It is axiomatic that economic development does not flourish in a climate of uncertainty. In this regard, the uncertainty of resource ownership becomes a barrier, primarily in economic terms. This may be demonstrated in both small and large scale development scenarios.

In the case of small scale development, resource ownership uncertainty may be more of a costly nuisance than an insurmountable barrier. In the case of the exploration now occurring in the Puna District, there is increasing interest in development. The eventual end use of these efforts is uncertain. However, regardless of any geothermal resource ownership issue or uncertainty, exploration with an eye towards commercialization is taking place. It has been suggested by some close to these efforts that either the ownership question is irrelevant because someone will eventually be paid for the resource or, at worst, the ownership question is costly and time consuming in that it takes an expenditure of development resources to negotiate multi-contingency leases. These "inconveniences" contribute to the overall effort required of a developer to explore and commercialize geothermal resources in Hawaii.

For those interested in large scale development, the uncertainty associated with resource ownership is an additional risk factor which, in combination with other risks, makes their entry into immediate large scale commercialization activities less attractive. These potential developers, such as large oil companies, would be investing large sums of their stockholders money in a venture which, at this time, has an uncertain potential and market (i.e., the size and potential of the reservoir is unknown and the current market for large scale power production is uncertain). In this light, potential developers might see the time and expense of negotiating multi-contingency leases with various potential resource owners as one more cost which makes their entry into geothermal resource development prohibitive at this time.

#### E. Resolution of Ownership Uncertainty

It has been suggested that in terms of expediting geothermal resource development, it is irrelevant how the question of resource ownership is resolved, so long as it is settled (J.M. Energy Consultants, 1979). Establishing resource ownership would tell potential developers who they have to deal with and reduce the time, and therefore, the expense of lease negotiations.

The process which will be used to resolve the ownership question is unknown. Many agree that a court decision would be time consuming and costly. However, if the geothermal resource is seen as highly prized and some parties feel disenfranchised, litigation may be unavoidable.

Kamins (1979b) suggests that if litigation is the ultimate decision process, the courts may make their decision more on issues of social policy than on sketchy and non-dispositive case law. In this regard, Kamins implies that the judicial level which finally decides the matter will have a significant impact upon the decision.

The Hawaii Supreme Court has recently shown a receptivity to social policy arguments, while in parallel cases regarding ownership of natural resources, the Federal District Court in Hawaii has been more protective of private property rights under the 14th Amendment (Kamins, in Seigel, 1980).

## F. Surface Land Ownership Patterns and Rights

There are two broad issues involving surface ownership. The first concerns the type of surface deed or conveyance. This may indicate the ownership of any geothermal resources. The second issue is the rights of the surface owner in the case which grants resource ownership to the state.

Should the state be held to be the resource owner, the rights of the surface owner are well protected by the state as provided in Regulation 8 (Department of Land and Natural Resources, 1978). This regulation allows the surface owner first option at any development operation. However, if the surface owner does not apply for a development lease within a specified period, the state can open up the right to development to the public. The California experience suggests that the practice of allowing development in the absence of the surface owner's consent may prove problematic, causing long and costly court involvement. In this regard, it has been suggested that Hawaii permit development only in the case of surface owner consent (J.M. Energy Consultants, 1978).

In addition to having the first right to develop, the surface owner is further protected by the Regulation 8 requirement that a bond be posted by the leasee to compensate the surface owner to "the full extent of the damage caused" by any development activities. An arbitration process is also provided if the leasee and the surface owner cannot agree on the amount of rentals and damages which are to be paid.

## **XII. LOGISTICS AND INFRASTRUCTURE**

### **A. Introduction**

Geothermal resource development will generally occur in four phases: resource exploration and field definition; field drilling; construction of end use facilities; and operation and maintenance of facilities. Each phase has varying physical and service requirements. Logistically, the availability of raw materials, construction services, transportation services, and manpower must be considered. Infrastructure considerations include the adequacy of existing roads; water, power and sewage systems; and electrical transmission facilities. This section addresses the major logistic and infrastructure requirements of the four phases of geothermal resource development in Hawaii.

### **B. Geothermal Resource Exploration and Field Definition Phase**

The process of locating and defining commercial quality geothermal resources may be time consuming and involve a degree of trial and error. As yet, exploratory drilling is the only sure means available to define the size and quality of geothermal fields. The exploration processes of site surveying and exploratory drilling requires only limited logistics and minimal infrastructure.

### **C. Site Survey**

The initial identification of a potential geothermal resource site requires a small number of skilled professionals utilizing specialized equipment and techniques. Geophysical and geochemical studies may use satellite and airborne sensing techniques as well as on-site studies to investigate surface geology, electromagnetic characteristics, gravity variations, and groundwater temperature and geochemistry. The University of Hawaii, through the Hawaii Geothermal Program, Hawaii Institute of Geophysics, and School of Geology can provide much of the expertise and technology for these investigations. Should a large energy resource development company, such as any one of the oil companies which has expressed an interest in geothermal energy development in Hawaii, decide to get involved, they would have their own staff and resources for exploratory studies.

Minimal site access may suffice for initial exploratory work, and be achieved by foot, all-terrain vehicle, and helicopter. However, exploratory drilling, which is required to confirm and define the boundaries and capacity of a potential field, demands more developed access.

#### D. Exploratory Drilling

The drilling of exploratory wells is similar to drilling in the field development phase. It may be on a smaller scale and perhaps to shallower depths. Portable amenities can usually be provided for dwellings, power, water, and sewage. Roads of adequate quality to transport drilling rigs, materials, and personnel to drilling sites will be required. Existing local roads will probably suffice for the limited transportation of heavy equipment and personnel required for exploratory drilling. As drilling sites can be reasonably self-sufficient, there will be only minor demands on local community services and resources for this phase.

#### E. Field Drilling Phase

Drilling wells, in addition to any existing exploratory wells, may be required to fully exploit an identified geothermal field. The extent of development of the field will depend on the extent and nature of the resource, as well as the type and scale of end use. The requirements for this phase are essentially the same as for those discussed with exploratory drilling. If field drilling takes place at a grand scale and over a short period of time, the need to import labor, equipment, and materials will increase. Accompanying this will be a need to bolster local infrastructure to handle increased road traffic, demand for housing and services, and demand on existing material transportation services.

Most sites identified by the Hawaii Institute of Geophysics as having potential geothermal resources of commercial quality in Hawaii are in rural areas. As such, existing infrastructure may not be adequate to accommodate a significant increase in utilization. This would pose a barrier to commercializing geothermal resources only if the rate of development exceeds what existing community resources and infrastructure can support. La Perouse Bay on Maui, for example, is one potential geothermal resource site which has no improved roads. This, in conjunction with limited services, transmission lines, and available manpower would impede the rate of field development there.

A possible barrier to full development of a geothermal field in a rural Hawaiian community is the capacity of the existing community to absorb a temporary population increase due to labor in-migration. Demands on housing, retail trade, and community services may be taxing.

#### F. End Use Facilities Construction Phase

The construction of end use facilities for commercializing geothermal resources in Hawaii is not unlike the construction phase of most other development endeavors. It will require laborers, equipment, and materials. Construction will be easiest when done near existing construction services, material distribution centers, and labor pools. The demands on local infrastructure and resources will be dependent on the scale and time frame of a project. Transmission facilities will be required to transport the resource from wells to an end use facility and for the transmission of electricity generated. Provisions will also be required for the transportation of raw materials and finished products to and from direct use facilities.

The production of electricity is one likely end use for the commercialization of geothermal resources in Hawaii. Again, logistical considerations and impacts on existing infrastructure will be dependent upon the scale of a construction project. The present 3 megawatt generator at the Hawaii Geothermal Project, Abbott Well, has not required the installation of significant new transmission lines, nor significant importation of construction equipment or labor. If the present proposal to develop a 25 megawatt generating facility in Puna is successful, there will be a need for improved transmission lines, in addition to construction of the facility and a geothermal well inter-connection system.

In anticipation of the full development of the Puna field, the Hawaii Electric Light Company is considering the installation of a high-capacity high-tension electrical line system over the saddle between Mauna Loa and Mauna Kea to transmit electricity produced in Puna to the west side of the Big Island. This would be a significant endeavor which would put additional demands on existing development and construction resources. In this regard, it is important to consider the logistical and infrastructural demands of constructing secondary and ancillary facilities associated with a geothermal resource end use facility.

If geothermal resources are commercialized for direct use applications such as papaya drying or ethanol production, transportation systems for raw materials and finished products may need to be improved. There is presently some concern that increased use of roads may cause accelerated

deterioration. This impact may be minimized if raw materials are available within close proximity to the end use facility. Construction of adequate facilities, such as roads, during the construction phase will reduce the potential of infrastructure inadequacies becoming a barrier to successful commercialization during the operation and maintenance phases.

The influx of a large, temporary construction workforce into a rural Hawaiian community is an important consideration to commercializing geothermal resources. This larger population will put increased demands on existing housing, police and fire services, retail trade, municipal water and sewage systems, and other community resources. To the extent that end use facility construction occurs at a rate which can be accommodated by the existing community, this effect will be minimized.

#### G. Operation and Maintenance Phase

Logistic and infrastructure requirements for the operation and maintenance phase of a geothermal end use facility are dependent primarily on the nature of that facility. Generally, electrical generation facilities will require few workers and place few direct demands on local services and resources.

Once constructed, an electrical generation facility requires, primarily, only that geothermal resources be piped to the facility and that the electricity be transmitted. As such facilities are highly automated and their operation mainly requires system monitoring with occasional servicing. As such, demands on local infrastructure are minimal.

The operation and maintenance of a direct use facility has higher logistic and infrastructure requirements than one for electrical generation. In addition to potentially greater direct employment of facility workers, secondary labor will be required in the transportation of materials and end products to and from a direct use facility. Tertiary impacts may be expected in infrastructure maintenance, such as roads and material transportation systems.



### **XIII. LEGISLATION AND PERMITTING**

#### **A. Introduction**

This section presents an overview of significant Federal and State legislation and permitting requirements that may impact the commercialization of geothermal resources in the State of Hawaii. Emphasis is placed on the immediate permits, regulations, and approvals possibly required, specific to geothermal resource development in Hawaii, as a result of these actions.

#### **B. Federal Legislation**

There are numerous Federal legislative actions that may impact commercialization of geothermal resources in Hawaii. Discussed here are those which are most significant and immediate.

Federal laws which may affect the siting of geothermal energy facilities in Hawaii include the:

- o Coastal Zone Management Act
- o Historical Preservation Act
- o Endangered Species Act
- o Floodplain Management Act
- o Rivers and Harbors Act
- o National Environmental Protection Act
- o Federal Water Pollution Control Act, as amended
- o Clean Air Act
- o Resources Conservation and Recovery Act
- o Noise Control Act
- o Geothermal Steam Act
- o Geothermal Loan Guaranty Act
- o National Energy Act
- o Geothermal Energy Act of 1980

The last four statutes listed are particularly important to geothermal resource development and utilization.

The Geothermal Steam Act of 1970 gives the Secretary of the Interior the authority to issue leases for the development of geothermal resources for all federal lands, including reservation lands. Bidding procedures are established for lands within Known Geothermal Resource Areas (KGRA). The Bureau of Land Management is responsible for conducting Federal lease sales. National park, recreation and wilderness lands cannot be leased.

The Geothermal Loan Guaranty Act established the Geothermal Loan Guaranty Program in 1974. The act provides for a Federal guaranty of repayment of commercial loans obtained for geothermal resource development. The program is administered through the U.S. Department of Energy. The intention of the legislation is to reduce the financial risk to a developer pursuing geothermal resource development.

Under the National Energy Act, there are two statutes which are particularly important to geothermal resource development. The Energy Tax Act of 1978 provides for a variety of tax benefits for developing or using geothermal resources. The Public Utilities Regulatory Policies Act of 1978 (PURPA) provides for the interconnection of electricity, produced by small producers and from renewable resources, into existing transmission facilities.

The Geothermal Energy Act of 1980, which is Title VI of the Energy Security Act (P.L. 96-294) provides loans for geothermal reservoir confirmation, and loans to determine the commercial feasibility of development. There have been no appropriations yet, and under the new administration, funding is uncertain.

Depending upon the site, project description, and end use of geothermal resource development, different laws apply and, therefore, a variety of cumulative impacts are possible. Further, common bureaucratic delays may arise over uncertainties or conflicts within and between agencies as to jurisdiction, authority, and regulations.

The general tenor of Federal legislation regarding the commercialization of geothermal resources is currently pro-development. However, geothermal resources are only present in limited regions of the United States, and as one of many alternate energy possibilities, are not the primary focus of national energy efforts. It is not yet clear how geothermal energy funding and expected production are intended to interact with existing energy programs and other alternate energy programs. This lack of an integrated national energy plan may create barriers to the immediate commercialization of geothermal resources by setting alternate energy programs in competition for Federal monies and aiding legislation.

### C. State Legislation

A variety of state legislation will impact the direction and pace of commercialization of geothermal resources in Hawaii. Much of this legislation is designed to control general development in the state. Included is the establishment of state and county plans, land use controls, and health and environmental protection mechanisms. Energy legislation has been enacted to guide the state towards its goal of decreased dependency on imported oil. Some of the energy legislation is specific to geothermal resources while other statutes relate to general energy production and distribution.

State legislation which may significantly affect the siting of geothermal energy facilities includes:

H.R.S. Ch. 205	"Land Use Law"
H.R.S. Ch. 205A	"Coastal Zone Management Act"
H.R.S. Ch. 343	"Environmental Protection Act"
H.R.S. Ch. 226	"Hawaii State Plan"
H.R.S. Ch. 182	"State Mineral Rights"
H.R.S. §246-34.7	"Alternate Energy Tax Exemption"
H.R.S. Ch. 269	"Public Utilities Commission"
H.R.S. §269-27.2	"Utilization of Electricity From Non-Fossil Fuels"
H.R.S. 269-27.1	"Establishment of Geothermal Rates"

In 1961, Hawaii adopted a landmark land law (H.S.L. 1961, Act 187). The law, now incorporated into H.R.S. Ch. 205, established the State Land Use Commission (LUC), and charged it with classifying all land into one of four districts: Urban, Agricultural, Rural, or Conservation. The counties have been given authority to enact stricter regulations and to zone the land within the Urban, Agricultural, and Rural Districts. The counties have sole authority in the Urban District, and share jurisdiction in the Agricultural and Rural Districts with the LUC. The State Department of Land and Natural Resources (DLNR) regulates uses in the Conservation District. Any development in the state must conform to the permissible uses within each of these districts. The Environmental Protection Act was passed in 1973 (H.R.S. Ch. 343). State Environmental Impact Statements are required certain situations.

Hawaii also has an extensive development planning scheme. The Hawaii State General Plan (H.R.S. Ch. 226) calls for at least twelve State Functional Plans, County General Plans, and County Development Plans. State Functional Plans and county plans are being written and approved at this time.

Some legislation is specific to energy and geothermal resource development. Most of it has been written in an effort to reduce development uncertainties, secure the State's claim to resources, and encourage development of alternate energy sources. In 1974, the Hawaii Legislature amended the statutory definition of "minerals" to include geothermal resources (H.R.S. §182-1). This legislation has an effect on which permitting and approval requirements must be met. Development delays may be experienced, depending on the resolution of ownership and Hawaiian Rights issues associated with this legislation.

H.R.S. §246-34.7, passed in 1976, allows building improvements which utilize alternate energy to be exempt from property taxes. This provides a direct incentive to utilize alternate energy resources, including geothermal.

H.R.S. Ch. 269 is concerned with the role and authority of the Public Utilities Commission. H.R.S. §269-27.2, passed in 1977, allows power generated from non-fossil fuels to be exempted from Public Utility Commission (PUC) regulation, if the energy is used by the producer or sold directly to a public utility. It also authorizes the PUC to require public utilities to purchase surplus power from such producers. H.R.S. §269-27.1, passed in 1978, gives the PUC the authority to regulate the pricing of steam and electricity produced from geothermal resources. Rules and regulations under this Section are being written. Although some of these laws put considerable time and manpower demands on a developer, in themselves, they do not pose serious obstacles to future geothermal resource development and utilization.

Present legislative actions which provide incentives and simplification of integration into existing energy systems are not enough to counter the present mismatch of resource and market. For example, the peak electric demand for the Big Island is roughly 85 megawatts. Projected demand increases for the next few years are expected to be easily filled by present proposals for electrical production from sugar company biomass generators. Present regulations prohibit the use of "unproven" sources for base-load electrical production without "proven" source backup. This means that if geothermal resources are developed that could provide Hawaii County with its electrical base-load, the

utility would still be required to have generation facilities capable of producing that base-load power should the alternate source fail. Dependable electrical production from geothermal resources in Hawaii is still to be demonstrated. As such, there is understandable hesitancy on the part of private enterprise to make large capital investments just to reduce the State's dependency on oil.

D. Permits, Regulations, and Approvals

Legislative actions require appropriate mechanisms to carry out their intent. With regard to geothermal resource development, these mechanisms are frequently in the forms of rules and regulations, permitting, and approval requirements. In Hawaii, the permit and approval processes for geothermal resource development and subsequent utilization can be time consuming. The number of permits required, agencies involved, attendant studies, assurances, and plans is dependent upon the exact nature of the project, its location, and its financing.

Agencies and bodies that may be involved in regulating and approving geothermal resource development and utilization include:

1. State Level

Board of Land and Natural Resources (BLNR)  
Department of Land and Natural Resources (DLNR)  
Land Use Commission (LUC)  
Department of Planning and Economic Development  
(DPED)  
Department of Health (DOH)  
Environmental Quality Commission (EQC)  
Public Utilities Commission (PUC)

2. County Level

Mayor's Office  
County Council  
Planning Commission  
Planning Department  
Department of Public Works

The efficacy of existing regulations and permitting processes in controlling geothermal resource development in Hawaii is not known. This is due to the lack of experience in using these control processes for this purpose.

By request of the Governor, the Inter-Agency Task Force for State Permit Simplification has been formed. Its report with recommendations for streamlining and improvements in the coordination of permitting and approval procedures is expected in the spring of 1981. For now, with regard to geothermal resource development, authorities are depending upon existing developmental control mechanisms until specific geothermal resource development concerns express themselves.

The lack of experience with geothermal resource development by decision makers and agency staffs in Hawaii may present an impediment to commercialization of the resource. Many public and agency officials have voiced a need for increased staffing and training to handle the anticipated demand for permits and approvals for geothermal resource development. To the extent that this need is unmet, permitting and approval processes may be delayed.

The major permitting and approval processes that will impact the development of geothermal resources in Hawaii are summarized in Figures 12 and 13. There is no clear coordination or order of approval among these processes. The order shown is that which is most usually observed.

There are essentially two levels of consideration in the permitting and approving of geothermal resource development proposals, distinguished mostly by scale. The first is exploration to define the extent and boundaries of the resource, and involves a comparatively small number of wells. The second is development of an established resource for commercial use. This generally involves more wells, land, and manpower, and implies additional impacts. The permit and approval process is involved at both levels, but is potentially more encumbering at the level of commercial development.

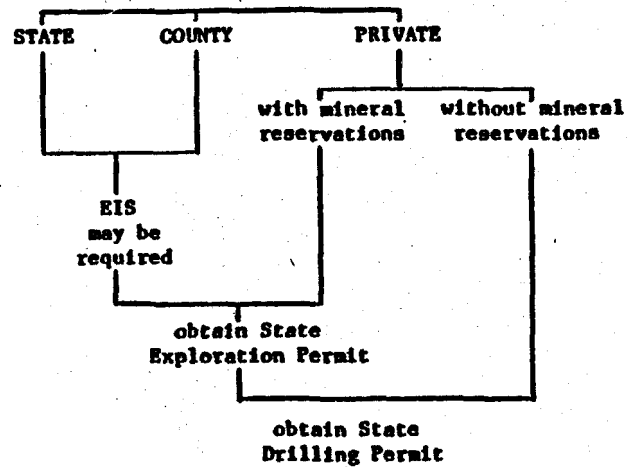
General development control mechanisms such as environmental protection regulations, land use controls, and Federal program requirements are the principle means of regulating geothermal resource development and facility siting in Hawaii. These general controls are supplemented by Regulation 8, "Regulations on Leasing of Geothermal Resources and Drilling for Geothermal Resources in Hawaii," which was adopted in June 1978, by the State Department of Land and Natural Resources.

Geothermal resource end use will be regulated, in part, by the Public Utilities Commission. In addition to its present powers over utilities and power generation, the pricing and transmission of steam and electricity produced from geothermal resources are to be regulated, although specific rules and regulations are yet to be worked out.

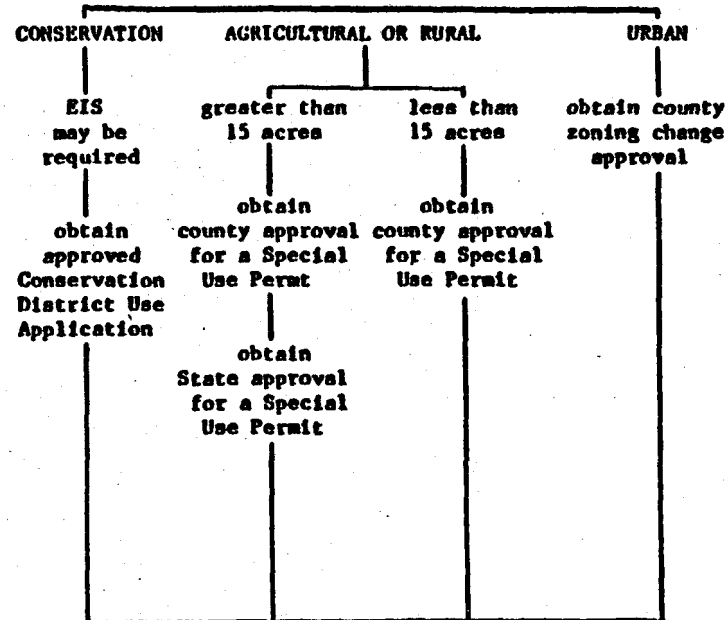
FIGURE 12

PERMITTING FLOWCHART FOR EXPLORATION OF GEOTHERMAL RESOURCES IN HAWAII

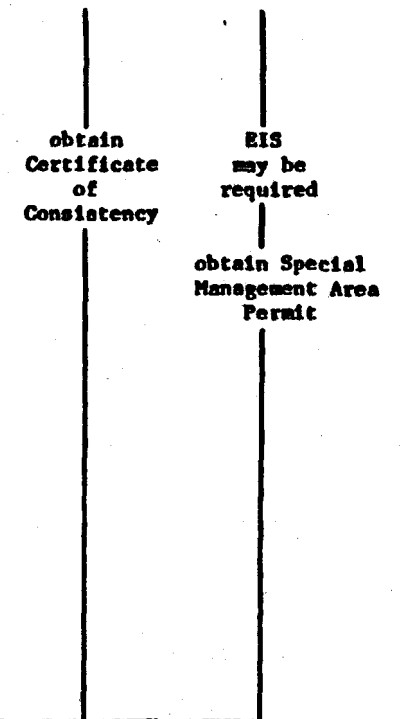
CHECK SURFACE OWNER'S MINERAL RIGHTS



CHECK STATE LAND USE DESIGNATION



CHECK COASTAL ZONE MANAGEMENT AREA



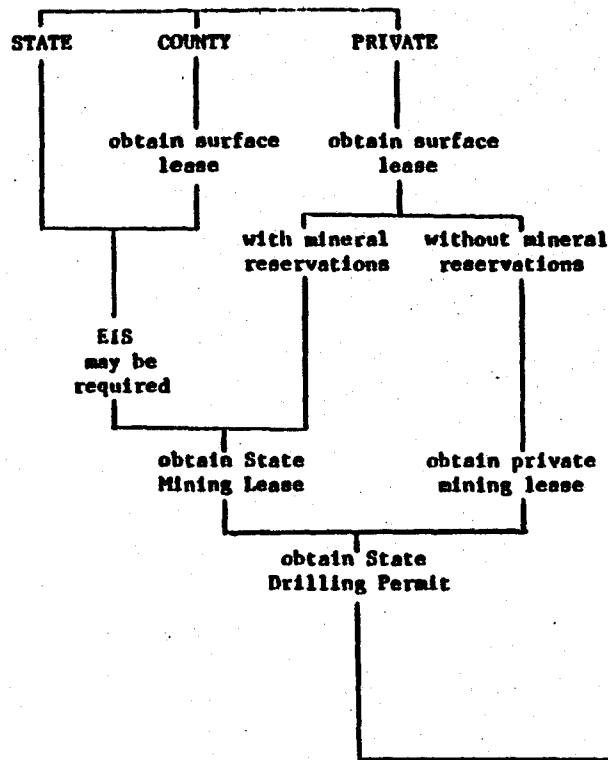
obtain building and grading permits

Source: Matteson and Rae Associates, Inc.

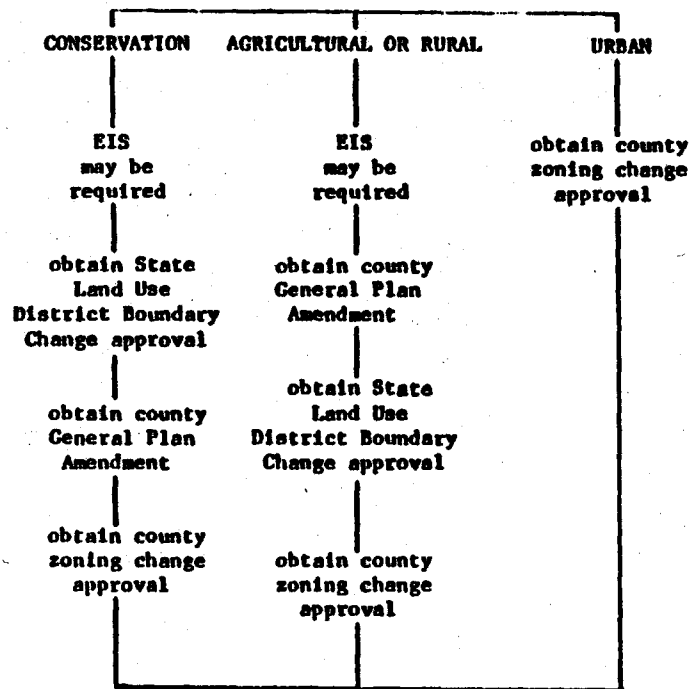
FIGURE 13

PERMITTING FLOWCHART FOR COMMERCIAL DEVELOPMENT OF GEOTHERMAL RESOURCES IN HAWAII

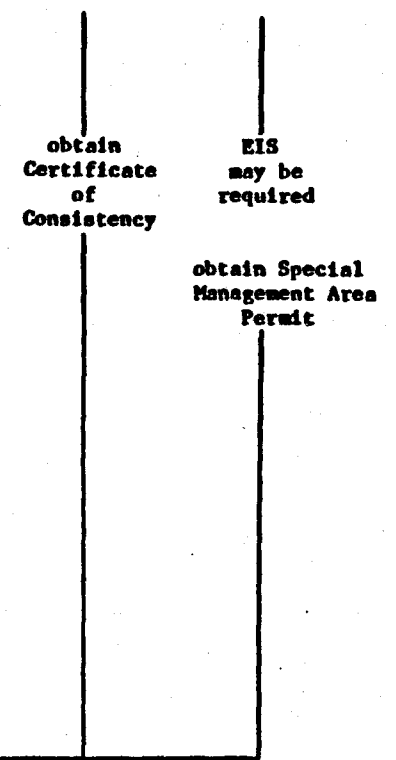
CHECK SURFACE OWNER'S MINERAL RIGHTS



CHECK STATE LAND USE DESIGNATION



CHECK COASTAL ZONE MANAGEMENT AREA



obtain building and grading permits

Source: Matteson and Rae Associates, Inc.



#### **E. Environmental Impact Statement Requirements**

The National Environmental Protection Act of 1969 (NEPA) has provided the basis and incentive for many contemporary environmental statutes. The enactment of H.R.S. Ch. 343 in 1974 made Hawaii one of the first states to enact its own environmental impact law. These actions reflect the concern in Hawaii for the preservation of the natural beauty and environment unique to the islands, and the need for adequate mechanisms to influence and control development.

Under H.R.S. Ch. 343, an Environmental Impact Statement (EIS) is required in five situations:

1. For any proposed action within a Conservation District;
2. For a site listed on the State Register of Historic Sites;
3. Within the shoreline area, as defined in H.R.S. §205-31;
4. For any proposal requiring the use of state or county lands or funds; and
5. For any action requiring an amendment to a County General Plan.

Under NEPA, an EIS may be required for any action or proposal which involves Federal monies, land, or permissions. A single EIS can usually be written to satisfy the particular requirements of both Federal and State laws.

The usual procedure for determining if an EIS is required is to submit an Environmental Impact Assessment (EIA) with the permit applications subject to the requirement. An EIA is a more general examination of potential environmental impacts than an EIS. The permit-granting agency will make a determination as to the necessity of an EIS, based on the information contained in the EIA. If it is determined that there will be no significant environmental impacts, a Negative Declaration may be granted. This relieves the applicant from the requirement of preparing an EIS. However, it can be expected that an EIS will be required for any geothermal commercialization project in the early stages of development in Hawaii. In the interest of saving time, an EIS should be submitted with permit applications as appropriate.

## F. Health and Environmental Protection Requirements

The Environmental Controls Panel of the Federal Inter-agency Geothermal Coordinating Council has investigated the availability of existing environmental controls for geothermal energy systems and assessed them in terms of their impact on the commercialization of geothermal resources. The principle health and environmental concerns identified with geothermal resource development and utilization are air emissions, liquid discharges, solid wastes, noise, subsidence, seismicity, and hydrological alteration. The panel felt that environmental problems could "pose obstacles to the commercialization of geothermal resources." Presently, environmental controls are not fully available to address these potential problems. The panel's recommendations call for increased research efforts in these areas (Environmental Controls Panel, 1980).

The Environmental Protection Agency, under the Clean Air Act, may establish standards for geothermal H<sub>2</sub>S and other emissions and may require the application of best available control technologies. However, no Federal geothermal emission standards have yet been set.

Surface water discharges are controlled by the National Discharge Elimination System under the Federal Water Pollution Control Act. Subsurface injection of waste and geothermal fluids requires a permit from the Department of Land and Natural Resource, per Regulation 8 of that Department. This is in accordance with the Federal Safe Drinking Water Act.

Noise may be a problem during both the drilling and operation phases of geothermal resource development and utilization. However, there are currently no regulations or standards for noise except for the Occupational Safety and Health Act which require ear protection for workers.

The general lack of health and environmental protection regulations and standards is a potential barrier to accelerated geothermal resource development. A potential developer is at a disadvantage in the feasibility phase of planning as he may not be able to accurately project the costs and possible encumbrances of required control mechanisms.

#### XIV. LAND USE CONTROLS

##### A. Use of Federal Lands

The Federal government owns approximately 8 percent of the lands on the Island of Hawaii, and 3 percent of the lands on Maui (State Data Book, 1980). Most of these lands are in National Parks, and are unlikely to be developed. However, a brief overview of the permitting requirements is provided.

Should a developer desire to use Federal lands for exploration and potential development, a Notice of Intent must be filed with the appropriate Land Management Agency prior to the leasing of the land. An approval to explore may then be granted. Upon completion of exploration, the Land Management Agency, under whose jurisdiction the land in question lies, decides whether to designate the land for competitive or non-competitive bidding. If the area is designated as a Known Geothermal Resource Area by the U.S. Geological Survey (USGS), it will be placed on a list of other Known Geothermal Resource Areas, and prioritized for processing. If it is not high on the priority list, a delay may be experienced in acquiring a lease. If the land is designated under the non-competitive leasing system, only a non-competitive application is required. This process is potentially less time consuming than the competitive bidding process. An Environmental Impact Statement may be required to obtain a lease.

Upon acquisition of a lease, the developer is required to submit a Plan of Operations and an Application for Permit to Drill to the USGS before full scale drilling may commence. To proceed with development, a Plan of Development and Plan of Injection must be submitted. An Environmental Assessment will be conducted by the USGS, and an Environmental Impact Statement may be required. After a year of environmental baseline data collection, a Plan of Utilization and a Plan of Production will need to be submitted. Again, an Environmental Assessment, and perhaps an Environmental Impact Statement, will be conducted before production may begin.

##### B. State Land Use Designations

One of the major determinants in the permitting process for any development in the State of Hawaii is the State Land Use Designation for the proposed site. Four land use designations have been established.

Lands in Conservation Districts include watersheds, forests, parks, and wilderness areas. Uses of land within a Conservation District are governed by the Rules and Regulations of the State Department of Land and Natural Resources (DLNR). The development of a commercial endeavor, such as a geothermal resource production field, is not a permissible use in this district, and would require a Land Use District Boundary Amendment. However, geophysical and geochemical studies, as well as exploratory drilling, may be allowed. Such activities would require an approved Conservation District Use Application (CDUA). CDUA's are submitted to DLNR and approved by the State Board of Land and Natural Resources.

Any and all uses permitted by the counties, either by ordinance or regulation, are allowed in the Urban District, subject to any conditions imposed by the State Land Use Commission. Under present permissible uses, commercial uses such as geothermal resource development, will have to be located within the Urban District.

The principle county controls within the Urban District are zoning laws. The nature of the development will dictate the exact zoning designation. No potential sites identified by the Hawaii Institute of Geophysics lie within an Urban District. A zoning change approval will be required by the county subsequent to a Land Use District Boundary Amendment to Urban by the Land Use Commission. Rezoning applications must be made to the County Planning Department, which reviews the proposal and makes recommendations to the County Planning Commission for approval. The County Council and Mayor must also approve all zoning change requests.

Agricultural and Rural Districts are under the jurisdiction of the state and are administered by the counties. Agricultural lands include those with capabilities for intensive cultivation. Not all Agricultural lands are being used for agriculture; many have already been subdivided for residential use. This is notably true in the Puna area of the Big Island. Rural lands are defined as lands primarily comprised of small farms mixed with low density residential lots which have a minimum lot size of one-half acre.

A Special Use Permit may be required by the county for activities in the Agricultural and Rural Districts. For proposals of less than fifteen acres the County Planning Commission may issue a Special Use Permit. For proposals concerning fifteen or more acres the State Land Use Commission must also act on the application. In any event, public hearings are required.

The Commission also has the option of denying the Special Use Permit and requiring the applicant to apply for a County General Plan Amendment. Given the present governmental and political support, it seems likely that most geothermal resource exploration will be granted under Special Use Permits. To date, all geothermal activity has been proposed in Agricultural Districts, and only for exploration. However, when these exploratory wells are commercialized, a General Plan Amendment will be required to comply with the permissible use within the Land Use District.

C. Permitting Procedure for Geothermal Resource Development Which Will Require a County General Amendment

Each county is to have its own General Plan. These, in conjunction with County Development Plans and State Plans, are designed to guide the growth and development of each county. Any proposed development which is inconsistent with the General Plan will require a General Plan Amendment before the project may begin. Given the locations of potential geothermal resources, it can be expected that General Plan Amendments will be required for commercializing an identified geothermal resource. This would include using existing exploration wells for commercial use as well as drilling supplemental wells and building end use and transmission facilities.

An amendment to a County General Plan requires an Environmental Impact Statement. Proposals for geothermal resource development will probably not have the benefit of a negative declaration. The recent public and contested hearings for a Special Use Permit for exploratory drilling in Puna are evidence of this.

The process of approval to commercially develop a geothermal resource on a site which requires a County General Plan Amendment is as follows:

1. A request for an Amendment is filed with the County Planning Department. An Environmental Impact Assessment is required from which the Director will make a determination whether an Environmental Impact Statement will be required. The application is reviewed by the Planning Department, and sent on to the County Planning Commission, with the Department's recommendation.

Approximate time required: 4-6 months.

2. The application is then acted upon by the County Planning Commission. Subsequent to Commission approval, the Planning Director forwards the request to the County Council for approval.

Approximate time required: 6-8 months.

3. A State Land Use District Boundary Amendment application to the State Land Use Commission must be submitted and approved. This is essentially the same information required by the county but may involve amendment actions in the process.

Approximate time required: 8-12 months.

4. The proposed site must now be rezoned by the county. This application is filed with the Planning Department for rezoning. Approval is required by the County Council.

Approximate time required: 4-5 months.

5. Final plans for plan approval, building plans for a building permit, and possibly, construction plans for a grading permit are then submitted to the Planning and Public Works Departments for issuance of their respective permits.

Approximate time required: 1-2 months.

The approximate time for completion of each step is based on information from the Hawaii County Research and Development Department. The time from initial application to final approval is thus estimated to be 23-43 months. However, these figures assume minimal delays in the approval processes. They do not reflect delays due to suits or challenges in the Environmental Impact Statement process. Either of these could result in delays of unpredictable length.

#### D. Coastal Zone Management Program Requirements

Under H.R.S. Ch. 205A, all lands in Hawaii except those in forest reserve are considered part of the Coastal Zone Management Program area. If a proposed project requires permitting or authorization by any Federal agency which comes under Coastal Zone Management (CZM) regulations, a Certificate of Consistency is required. This certification is granted by the State Department of Planning and Economic Development (DPED).

Special Management Areas, also part of the CZM program, are administered by County Planning Commissions. (In the City and County of Honolulu, the Department of Land Utilization has this authority.) Each Planning Commission has discretionary powers as to how much environmental information is necessary, i.e., whether an Environmental Impact Statement must be prepared. Minimally, an Environmental Impact Assessment is required. If an EIS has already been prepared, it will probably suffice in this process and should be submitted along with the application.

## XV. REGULATION 8

### A. Introduction

Anyone desiring to drill a geothermal well in the State of Hawaii is subject to the requirements of Regulation 8, "Regulations on Leasing of Geothermal Resources and Drilling for Geothermal Resources in Hawaii," of the Department of Land and Natural Resources, June 1978. At present, it is the only state regulation pertaining specifically to geothermal resource development in Hawaii.

### B. Leasing

Part I, "Leasing of Geothermal Resources," applies only to state lands or private lands with state mineral reservations. It sets forth the permits required for exploration, details on geothermal mining leases, procedures for leasing of state lands and reserved lands, surface rights and obligations, and mining under a lease. All leases are granted by the Board of Land and Natural Resources. Leases must be granted through competitive bidding, except that leases for production on reserved lands may be granted non-competitively to the occupier with two-thirds vote of the Board. The primary term of a lease is ten years. Leases may be renewed so long as geothermal resources or by-products are produced in commercial quantities. Leases may be held and renewed up to a maximum of 65 years. If at the end of the primary term geothermal resources are not being produced, or producing wells are shut in with no market, the renewal period is five years. Royalties to the state are to be no less than 10 percent and no more than 20 percent of the gross amount or value of the geothermal resources produced. The rate of royalty for any geothermal by-product is to be no less than 5 percent and no more than 10 percent of the gross proceeds received. The minimum acreage for a lease is 100 acres. The maximum acreage is 5,000 acres or 2,560 if the length of the tract is more than six times the width.

### C. Drilling

Part II, "Drilling for Geothermal Resources," applies to any drilling on any lands in the state, regardless of ownership. It describes necessary contents of an application, fee, bonds, placement, specification, record keeping, safety precautions, environmental protections, operation and maintenance, and abandonment of any geothermal well in



the state. Drilling permits are granted for a period of one year, with an extension period of 180 days. A performance bond is required of \$50,000 per well. Wells must be spaced no less than 100 feet from the outer lease boundary or from a public road, and located as prescribed by the Chairman of the Board of Land and Natural Resources. Permits are required for injection wells and well abandonment.

There are two divisions of the Department of Land and Natural Resources principally involved in the administration of Regulation 8. The Division of Land Management is primarily responsible for those portions of the regulation pertaining to leasing. The Division of Water and Land Development is responsible for the more technical aspects of the regulation, generally, those aspects are detailed in Part II.

Regulation 8 and the Geothermal Mining Lease have been written in anticipation of geothermal development in Hawaii. These regulations have been written based on knowledge of geothermal resource development in other areas of the world, and adapted to the Hawaiian setting.

#### D. Unitization

Regulation 8 addresses unitization but to a limited degree. Presently, there is no plan or requirement for unitization of geothermal developments in Hawaii. In California, there are specific rules and regulations that not only govern unitization, but require it. This provides for an effective means to manage the resource. The lack of clear geothermal resource management policies and comprehensive unitization regulations in Hawaii may present a barrier to the successful commercialization of its geothermal resources. There may be a hesitancy among developers to make large capital investments while there is uncertainty about their rights to a common resource.

XVI. PUBLIC UTILITIES COMMISSION

Approval must be obtained from the Public Utilities Commission (PUC) before electricity produced from geothermal resources may be sold to a public utility. PUC rules and regulations governing the pricing of alternate energy production and geothermal resource utilization are being written. Depending on the amount of electricity produced, the Federal Energy Regulatory Commission may be involved in approving interconnection into existing electrical grid systems.

Presently, the PUC is charged with setting rates for steam and electricity produced from geothermal resources. Again, the specifics of how this will be done are yet to be worked out. Regulation and permits that would apply to direct heat use include those associated with general industrial developments. These might be considered impediments to commercialization of geothermal resources only in that they require time to address.

## XVII. POLITICAL CLIMATE AND ENVIRONMENT

### A. Introduction

As is the case with most development issues, the political environment surrounding geothermal resource development in Hawaii contains both proponents and opponents, as well as groups and individuals who have not as yet become involved. This section identifies and discusses some of the major actors defining the political climate for the commercialization of geothermal resources in Hawaii.

### B. Federal Government

The Reagan administration is likely to have significant impacts on the future of energy development in this country. One action under consideration is to do away with the Department of Energy. The impact may be that the state will have to take a greater role in geothermal resource funding.

### C. State of Hawaii

The State of Hawaii, as expressed by the Governor through the Energy Resources Coordinator, views geothermal resource development as one option of many alternative-to-oil energy development proposals. State policy is intended to reduce Hawaii's dependence on imported oil and provide sufficient energy for increased economic activity and population growth. As such, it is necessarily concerned with any alternative which will advance these goals. The state is therefore supportive of geothermal resource development in concert with other alternative energy possibilities.

With regard to geothermal resource development, the state is providing financial and technical support through the Hawaii Natural Energy Institute and the Hawaii Integrated Energy Assessment Program and other efforts. The State's position is that the private sector should be responsible for exploratory drilling and ultimate commercialization. The state conceives its supportive role to the private sector as

one of information sharing and planning. This supportive policy and coordinative role is an enhancement to the eventual commercialization of geothermal resources in the state. It serves to prescribe the responsibilities and expectations of various participants, and establishes a forum within which constructive interaction may take place.

The state is also interested in supporting energy and general economic development by considering means to reduce bureaucratic restraints and constraints imposed by laws and regulations. Towards this end, the Governor has established the Inter-Agency Task Force for State Permit Simplification. If recommendations are made by this committee and implemented, the effect on geothermal resource development will be to expedite the permitting and approval processes associated with commercial development. This will be added incentive to the private sector to pursue exploration and development activities.

D. State Board of Land and Natural Resources (BLNR)

The State Board of Land and Natural Resources (BLNR) plays an integral role in the development of geothermal resources. Its responsibilities, through the Department of Land and Natural Resources, include permitting geothermal exploration and issuing geothermal mining leases on state and reserved lands, as well as permitting and regulating the drilling and maintenance of geothermal wells anywhere in the state. Therefore, most aspects of geothermal resource development will be subject to the purview of the Board.

BLNR is an appointed non-paid body and as such, it is difficult for all members to take enough time to be well acquainted with the issues and facts of all matters that the Board must consider. The Board has successfully adapted to this situation by depending on certain members for expertise. To the extent that the entire Board may become more fully informed as to the nature and impacts of commercializing geothermal resources in Hawaii, there will be greater efficacy by the Board on geothermal resource applications.

E. State Land Use Commission (LUC)

The State Land Use Commission (LUC) may have significant influences on the future development of geothermal resources in the State of Hawaii. This would come from its responsibilities to approve changes in State Land Use Districts and recommend changes in permissible uses within these districts.

All potential geothermal resource sites identified on the Islands of Maui and Hawaii are located in Agricultural or Conservation Districts. Presently, commercial geothermal development is not a permissible use within these districts. Therefore, commercialization of geothermal resources on either island will require a change in either the existing Land Use District Boundaries or a change in the permissible uses within these districts.

The LUC has demonstrated support for geothermal resource development by its approval actions associated with the granting of Special Use Permits for geothermal exploratory drilling on the Big Island. These approvals were subsequent to recommendations and approvals by the county. However, as commercial geothermal resource development will require major land use decisions and recommendations by the Commission, the Commission will become increasingly subject to greater pressure from a variety of interest groups. Given this anticipated greater involvement and the Commission's relative lack of experience in geothermal resource matters to date, it would serve successful geothermal commercialization to provide the Commission with an information program concerning geothermal resource development in Hawaii.

#### F. State Legislature

The Hawaii State Legislature has been a strong supporter of alternate energy development, including geothermal resource commercialization. This is evidenced by the State's instrumental role in the drilling and continued support of the Hawaii Geothermal Program - Abbott Well in Puna, on the Big Island. The legislature has also created tax incentives for geothermal resource commercialization, funding for investigations to identify potential resource sites, and continued financial support of both direct use application and electrical generation research and development.

Changes in legislative and committee composition due to recent elections are not expected to have a significant effect on legislative support for alternative energy development. Of greater importance is the legislature's degree of understanding of the wide range of issues and facts relating to geothermal resource development as one avenue of alternate energy development. Interviews with legislators active in energy development suggest that alternatives such as Ocean Thermal Energy Conversion (OTEC), or more familiar alternatives, such as biomass energy conversion, receive greater attention than geothermal resource proposals. These legislators concur that the legislature would benefit from a greater understanding of geothermal resource development and that the resources and opportunities required for this should be made available as soon as possible.

#### G. Maui County

Although Maui County is intensively engaged in an energy self-sufficiency planning process, considerations specific to geothermal energy development are rudimentary. As such, political interests and concerns have not had a chance to mature in regard to issues which inherently surround geothermal energy exploration and commercialization.

While specific geothermal issues have not as yet emerged in Maui County to any great degree, it is possible to discuss the general climate vis-a-vis alternative energy development which will influence any future geothermal resource commercialization on Maui. In this regard, the county supports efforts to develop alternative energy resources to lessen the county's dependence on imported oil and stimulate the local economy. Although county leaders are open to the possibility of geothermal energy development, wind farms and biomass conversion alternatives have predominated. Generally, the county might prefer geothermal energy to wind energy, as the resource promises to be more dependable and the county has greater control over its development through county land use decision making powers. (Wind farms are a permissible use in Agricultural Districts and hence beyond the land use controls of the county.)

Recently, private development interests have begun to seriously consider exploration of potential geothermal resource sites on Maui. As these projects and sites become known, it may be expected that pockets of opposition and support will form. Opposition might come from preservationist and other special interest groups, and may focus on the same types of issues which have emerged in the Puna District. Education of the general community to the potential benefits of development of geothermal resources may enhance smooth and expeditious commercialization.

#### H. Hawaii County

Hawaii County government has been actively supportive of geothermal resource development. The county appropriated some of the first monies to initiate the Hawaii Geothermal Program in the Puna District. More recently, a major bond issue has passed which will, in part, be used to improve infrastructure in the Puna District. These improvements are partially in anticipation of commercial development of the area's geothermal resources.

The Mayor is a proponent of geothermal resource commercialization on the Big Island. He favors accelerated development of commercial projects with continued research into potential direct use applications. He envisions commercialization of the island's geothermal resources as a welcome stimulus to the county's economy.

The County Department of Research and Development has expended considerable resources to investigate direct use applications of geothermal resources. These investigations have included fruit drying, ethanol production, and industrial steam applications. The county has also contributed funds to study the environmental impacts of manganese nodule processing. The attraction of such an industry would be an economic boon to the county. The county is careful, however, not to encourage economic growth at the expense of the unique island setting.

Pro-development policies of the county government are somewhat tempered by other influences. These manifest themselves at the district and neighborhood levels, mainly through groups which voice special economic and social concerns. At the district level, geothermal resource development was a 1980 campaign issue in which one candidate for County Council ran a predominantly single issue campaign against uncontrolled geothermal resource development.

Various community groups have established themselves as viable political forces by focusing on the issues surrounding geothermal resource development in the Puna District. Some groups, such as the Leilani Community Association, have opposed any resource development which may alter the character of their community. Other groups, such as the Puna Hui Ohana, have opposed geothermal resource development in the absence of a community based geothermal resource development plan. These groups, as well as unaffiliated individuals, have made their views known at public meetings and Planning Commission hearings. Active proponents of geothermal energy development in the area have been less quick to mobilize, although they have begun to come forward and make their opinions known.

The official forum for the airing of opinions and concerns in regard to specific geothermal resource development proposals has been the Hawaii County Planning Commission hearings for Special Use Permits for geothermal resource exploration. The Planning Commission has made a concerted effort to assure that all parties desiring to express a view have been heard and that their views have been fairly represented in the public record. The general sentiment in both Maui and Hawaii counties towards the commercialization of geothermal energy focuses on trade-offs. What benefits will the county and specific districts receive and what "costs" will they have to pay?

Both counties have suggested that energy from geothermal resource development should be used first in the county where it is commercialized, and then considered for exportation to neighbor islands. County governments can exert political influence in these matters as well as control over various land use decisions that will be required to commercialize geothermal resources.

The counties are quite cognizant of their role of promoting local interests first. This "home rule" issue is not unique to geothermal resource development. At times, it may appear that county versus state interests might pose barriers to cooperation; however, this may be minimized through the proposed State Energy Plan which calls for and provides a process encouraging coordination of state and county efforts.



## XVIII. STATE PLANS

### A. Introduction

Several state plans exist which are relevant to geothermal development planning. They are the Hawaii State Plan and the State Functional Plans for Energy, Agriculture, Conservation, Tourism, and Water Resource Development.

### B. The Hawaii State Plan

In 1978, the Legislature enacted Chapter 226 of the Hawaii Revised Statutes, the Hawaii State Plan. The purpose of the plan is to improve the statewide planning process, which is to articulate goals, objectives, and policies intended to guide the future development of Hawaii. As such, the Hawaii State Plan is necessarily concerned with the provision of energy.

The State Plan defines two energy objectives. The first is to provide dependable, efficient, and economical statewide energy systems capable of supporting the current and future needs of the people of Hawaii which includes moderate growth policies. The second objective is to provide increased energy self-sufficiency by decreasing Hawaii's dependence on imported oil. Timely and sound geothermal energy development is consistent with and supportive of both objectives.

State Plan policies in support of the energy objectives are to:

- o accelerate research, development and use of new energy sources;
- o provide adequate, reasonably priced, and dependable power to accommodate demand;
- o ensure a sufficient supply of energy to enable power systems to support the demands of growth;
- o promote prudent use of power and fuel supplies through education, conservation and energy-efficient practices;
- o ensure that the development or expansion of power systems and sources adequately consider environmental, public health, and safety concerns, and resource limitations; and
- o promote the use of new energy sources.

The number one priority action for energy use and development is to encourage the development of alternative energy sources. The geothermal resource is one such alternative found in Hawaii. Its commercialization would further state objectives and goals for Hawaii's energy future. The State Plan sets the stage for future geothermal resource planning.

## **XIX. COUNTY PLANS**

### **A. Introduction**

Although geothermal anomalies exist on several islands, this section addresses only the Islands of Hawaii and Maui. These islands have the greatest potential for near-term commercialization of geothermal resources. This does not preclude the possibility that development of geothermal resources on other islands may occur.

### **B. County General Plans**

Both Maui and Hawaii Counties have adopted general plans designed to guide the overall growth of the counties. They are broadly concerned with issues of land use, service provision, and resource allocation. The plans articulate goals and policies at the county level. While neither county plan contains specific information in regard to the potential of geothermal resource development, both establish goals and objectives in the areas of economic growth and energy provision. These are consistent with and supportive of development of this indigenous resource.

Each general plan also contains goals and objectives in the areas of environmental quality, historic preservation, housing, natural resources, public facilities, and recreation to name a few. As each general plan is revised, as is required periodically, each functional element will require updating in light of the current and projected status of geothermal resource development in the county. Additionally, general plan amendments will be required for commercialization of geothermal resources in Agricultural, Conservation, and Rural Districts.

### **C. County Energy Self-Sufficiency Studies**

Both the County of Maui and the County of Hawaii have prepared energy self-sufficiency studies which discuss policy options and technologies designed to move the counties in the direction of increased energy self-sufficiency. Both are excellent technical documents which need to be reviewed by developers prior to their submittal of project specific geothermal energy development proposals.

Maui County has adopted, by County Council resolution, a study entitled Energy Self-Sufficiency for the County of Maui (Hawaii Natural Energy Institute, 1979). The study serves as Maui County's Energy Self-Sufficiency Plan.

The plan reflects an understanding of Maui's current energy picture, its forecasted energy requirements, and its potential resources. The plan also contains, in Volume III, specific actions required to move the county in the direction of energy self-sufficiency.

Hawaii County has not yet adopted an energy self-sufficiency plan. Energy Self-Sufficiency for the Big Island Of Hawaii has been prepared by SRI International, with the aid of both energy and business consultants from the Big Island. The report is entitled Energy Self-Sufficiency for the Big Island of Hawaii. The report discusses current energy demand as well as forecasted requirements. Programs to promote energy production from indigenous sources, however, are discussed only in the broadest terms.

## XX. GEOHERMAL DEVELOPMENT RISKS

### A. Introduction

Paul Rodzianko of the Geothermal Energy Corporation, prepared a paper entitled "Financing Geothermal Development" for a "Special Short Course No. 9", presented by the Geothermal Resources Council in April, 1980. He discusses some of the fundamental issues and salient options for financing resource development.

"Geothermal is a capital-intensive industry. The utilization of the resource requires the construction of a powerplant, agrobusiness or industrial facility in addition to the investment in drilling. Since these are site-specific utilization investments, the investor in this phase of development must be assured that the resource on which the facility is being built will last as long as it takes to recover his investment. As a result, the investor is sharing the risk of the reservoir's projected performance through time, in some cases as long as thirty years."

### B. Dry Holes, Blow-Outs, and Inadequate Temperature

Charles Helsley of the Hawaii Institute of Geophysics, in a report entitled "Big Island Geothermal Plant" noted that "six wells were drilled before a good well was found in the Puna field. Until the complete field boundary is identified, a more realistic approach may be 50% dry holes." He estimates that twenty production wells will be required to serve a 50MW geothermal generation plant in the Puna District. He further estimates that a total of thirty wells or more may have to be drilled to achieve those twenty production wells at an average cost of \$2 million per well. It should be noted, perhaps, that any estimate of the number of exploration wells required to discover one which will become a production well must necessarily be provisional and tentative. Each geothermal resource area of the world demonstrates characteristics which are highly site-specific and even those wells which discover a geothermal resource are still subject to additional technical risks.

A report entitled The Lake County Economy: Potential Socio-Economic Impacts of Geothermal Development reports on geothermal resource development in Lake County California (which adjoins the famous Geyser's Field in neighboring Sonoma County). That report makes the following notation which relates to the risks of acquisition and exploration:

"Of the first twelve wells drilled by Thermal in the Big Geyser's Field (to 400 feet), three had poor cement casings and leaked surface water, one had a malfunctioning foot valve, one had insufficient steam, and one blew out."

An article entitled "Geothermal Exploration: Strategy and Budgeting" was written by Mr. Ronald C. Barr, then Chairman and President of the Earth Power Corporation, and reported in the Geothermal Energy Magazine issue of May, 1975. Mr. Barr reports in that article that "It is generally assumed that geothermal energy will be found 20 times more frequently as hot water than as dry steam." He further suggests that;

"Several knowledgeable industry sources generally agree that of 60 prospective targets, geothermal energy would be found in the following relative abundance:

Abundance:	Temperatures:	Utilization:
40	250-350°F	Process Heat
12	350-450°F	Electrical (Binary)
5	450°F	Electrical (Flash)
1	475°F	Electrical (Dry)"

#### C. Natural Hazards

The geologic hazards of primary concern to geothermal industry development in Hawaii are those associated with volcanic activity, seismic activity and tsunami inundation (tidal waves).

Even though all the islands in the Hawaiian chain have experienced volcanic activity during recent geologic history, the only historically active volcanoes in Hawaii are Haleakala (1790) on Maui, and Hualalai (1801), Mauna Loa (1975) and Kilauea (1979) on Hawaii. The most frequently active volcanoes are Kilauea and Mauna Loa and on this basis, the slopes of these volcanoes are considered to have the greatest hazard potential. The primary

products from a volcanic eruption are lava flows, drifting volcanic gases and particle and ash clouds. Although the volcanic eruption products (especially lava flows) can travel great distances from the eruptive vent, the areas of greatest hazard are generally within a few kilometers of the Mauna Loa and Kilauea summits and rift zones. The risks posed by volcanic eruptions to life are considered to be minimal; however plant facilities and large equipment are at some significant risk and hazard mitigation measures should be considered for installations in the more hazardous areas.

Seismic hazards in Hawaii include ground shaking, subsidence and extensional ground cracking, which are generally restricted to the rift systems and seaward flanks of Mauna Loa and Kilauea volcanoes. Mitigation measures should be considered for plant facilities located within these areas.

Tsunamis in Hawaii have been generated by both local seismic events as well as events occurring several thousand miles away around the Pacific Basin. Damaging tsunamis have occurred relatively frequently during historic times (approximately one every twenty years) and as a result, a tsunami warning system has been developed for Hawaii. The hazards associated with tsunamis are generally restricted to low lying coastal areas; recorded wave runup seldom exceeds 20 to 30 meters in altitude although higher occurrences have been reported in confined embayments and channelways. On this basis, the most cost effective mitigation strategy for tsunami hazard is placement of major plant facilities well above exposed shorelines.

Although some concern has been expressed in regard to the possibility of geothermal drilling inducing seismic or volcanic activity, it is considered highly unlikely that eruptive outbreaks or significant seismic movement could be generated by geothermal production or reinjection.

#### D. Regulatory Consideration

An assessment titled, "Geothermal Development Risks from San Diego Gas and Electric Company's Perspective," by C.R. Swanson of that company, was prepared for the Electric Power Research Institute during the summer of 1978. In addition to discussing technical and environmental risks Swanson makes the following statements regarding regulatory considerations and economic consequences:

"Since the regulatory process is tied so intimately to public and political pressure, the major regulatory risk is that currently favorable attitudes toward geothermal energy could change dramatically in a relatively short time."

E. Economic Consequences

The technical, environmental and regulatory considerations all lead eventually to potential economic consequences... it is difficult to judge the cost of geothermal power.

First, based upon SDG&E's own experience with geothermal to date, it appears that geothermal power will be fixed-cost intensive.

Second, based on SDG&E's discussions with the developers and our own experience with geothermal power plant design, it appears that the components of the total levelized busbar cost over the plant's operating life will be divided roughly into 25% for plant capital cost, 65% for the "fuel" (resource) cost and 10% for O&M cost for a 75% plant capacity factor. Thus, geothermal power costs are most sensitive to fuel charges and least sensitive to O&M costs, with capital costs intermediate... Whether geothermal plants will have a 20-year life or a 30-year life will not substantially affect the levelized busbar cost of power; although plant operating life has a significant influence on investment cost recovery by a utility and, thus, investment risk. This relates to the earlier-described regulatory risk which reflects the concern that regulators may later change their attitudes about geothermal and not allow a utility to recoup its investment if the reservoir depletes prematurely. Premature depletion is a greater risk to the utility investing in a plant than it is to the resource developer because the plant capital cost is significantly greater than the cost of reservoir development to support the plant.



## **XXI. BUSINESS PLANNING GUIDELINES**

### **A. Introduction**

This section offers guidelines to obtaining planning information on proposed projects which are viewed as commercially feasible. The guidelines incorporated in this section also set forth the sources of this information.

These project planning guidelines are discussed under the following headings:

- o State Geothermal Energy Development Activities.
- o Availability of Land in Geothermal Regions.
- o Financial Information.
- o Construction and Operating Costs.

### **B. State Geothermal Energy Development Activities**

The businessman should be aware of the local government activities directed toward commercialization of the geothermal resources. The ongoing activities are discussed below.

#### **State Department of Planning and Economic Development:**

- o Select economic and market studies.
- o Studies covering reports of geothermal surveys and technologies.
- o Studies covering related environmental issues.
- o Financial considerations and loan programs.

#### **County energy offices:**

- o Geothermal studies and reports.

#### **County economic planning offices:**

- o Economic and market studies.

#### **Hawaii Natural Energy Institute, University of Hawaii:**

- o Economic studies and technical reports on the HGP-A well and power plant in Puna.

#### **Hawaii Institute of Geophysics, University of Hawaii:**

- o Reports of geothermal surveys on all islands.

#### **State Department of Land and Natural Resources:**

- o State land leases.
- o Mineral rights and reservations.
- o Exploration and drilling permitting.

### C. Availability of Land in Potential Geothermal Regions

The important early step in exploration or business development is obtaining suitable land in or near the geothermal regions of the State. These regions, described in the preceding section, include large (several thousand acres) private and public land holdings in addition to smaller parcels (under one thousand acres). Information on ownership, location and taxes are available in government publications and private real estate offices, and in property management offices of the large holdings. The government agencies and large holdings where land information may be obtained are described below:

State Department of Planning and Economic Development:  
o State of Hawaii Data Book (Annual).

State Department of Agriculture:  
o Statistics of Hawaiian Agriculture (Annual).

State Department of Land and Natural Resources:  
o Annual Report.

University of Hawaii, Cooperative Extension Service  
Private Estates:

- o Alexander and Baldwin, Inc.
- o Amfac Properties
- o Bishop Estate
- o C. Brewer and Company, Ltd.
- o Campbell Estate
- o Castle and Cooke, Inc.
- o Theo. H. Davies and Company, Ltd.

#### D. Financial Information

It cannot be assumed that Federal funds for energy projects will be available during the next several years, therefore, private funding should be sought. However, Government loan guarantee programs can be assumed to be a source of funding support for industrial and agricultural projects. Government agency loan programs are described under appropriate headings below:

##### Small Business Administration:

- o Energy Loan Program; and
- Small Business Loan Guaranty Program.

##### State Sources

##### Department of Planning and Economic Development:

- o Hawaii Capital Loan Program.

##### Department of Agriculture:

- o Agriculture Loans; and
- Aquaculture Loans.

#### E. Construction and Operating Costs

Projects of a specific nature require information on construction and operating costs. Operating information dealing with markets, transportation, production, manpower and permits are discussed below:

##### 1. Construction

##### Project Type

##### Sources of Information

##### Agriculture

College of Tropical Agriculture,  
University of Hawaii.  
State Department of Agriculture.  
State Department of Planning and  
Economic Development.  
U.S. Bureau of Census, Census of  
Agriculture.  
U.S. Department of Agriculture,  
Soil Conservation Service.  
Hawaiian Sugar Planters' Association.  
Pineapple Growers Association.

##### Aquaculture

Aquaculture Development Program, DLNR.  
State Department of Agriculture.  
Oceanic Institute, Honolulu.  
Sea Grant Program, University of Hawaii.  
State Department of Land and Natural  
Resources, Fish and Game Division.

**Tourism**

Travel Industry Management Program,  
University of Hawaii.  
State Department of Planning and  
Economic Development,  
Tourism Office.  
U.S. Travel Service.

**Manufacturing**

State Department of Planning and  
Economic Development.  
Hawaiian Sugar Planters' Association.  
Chamber of Commerce of Hawaii.

**2. Markets**

**Project Type**

**Sources of Information**

**Agriculture**

Marketing Division, State Department  
of Agriculture.  
College of Tropical Agriculture,  
University of Hawaii.  
Economic Development Division, DPED.  
Hawaiian Sugar Planters' Association.  
Pineapple Growers Association.

**Aquaculture**

Aquaculture Development Program, DLNR.  
Department of Agriculture, Marketing  
Division.  
Sea Grant Program, University of Hawaii.

**Tourism**

Hawaii Visitors Bureau.  
Tourism Office, State DPED.  
Neighbor Island Visitor Bureaus.  
U.S. Travel Service.  
Commercial Airlines.

**Manufacturing**

Trade Associations.  
Hawaiian Sugar Planters' Association.  
Pineapple Growers Association.  
Papaya Administrative Committee.

**3. Transportation**

State Department of Transportation.  
State Department of Planning and  
Economic Development.  
Truckers Association.  
State Public Utilities Division,  
Department of Regulatory Agencies.

#### 4. Production (Operations)

<u>Project Type</u>	<u>Sources of Information</u>
Agriculture	Trade and Marketing Associations. State Department of Agriculture. Hawaiian Sugar Planters' Association. Pineapple Growers Association. College of Tropical Agriculture, University of Hawaii.
Aquaculture	Aquaculture Development Program, DLNR. Oceanic Institute, Honolulu. Sea Grant Program, University of Hawaii.
Tourism	Travel Industry Management Program, University of Hawaii. Hotel Association of Hawaii.
Manufacturing	Manufacturing Trade Associations.

#### 5. Manpower

State Department of Labor and  
Industrial Relations.  
State Department of Planning and  
Economic Development.  
State of Hawaii Data Book (Annual).  
U.S. Department of Labor.

#### 6. Permits

State Department of Health:  
o Construction and Operation  
Permit.  
o Variances to Pollution Controls.

Federal Environmental Protection  
Agency:  
o Federal lands.  
o Surface water impacts.

State Office of Environmental Quality  
Control:  
o Conservation Districts.  
o Coastal zones.  
o State and County lands.

**County Building or Planning**

**Departments:**

- o Building permits.
- o Grading permits.

**State Department of Transportation:**

- o Utility Installation Permit.

**County Building Boards of Appeal:**

- o Variances to building,  
plumbing, electrical codes.

**State Department of Land and Natural  
Resources, and County Department of  
Land Utilization or Public Works:**

- o Historic Site Review and  
Certificate of Appropriateness

**County Departments of Land  
Utilization or Public Works:**

- o Conditional use permits  
required for utilities in  
agricultural lands.

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